active solar water heating

For much of Alaska, the heating of domestic or commercial hot water using solar energy is an economic option to consider. This is due to several factors:

1. The cost of energy is high in most areas.
2. Although annual solar variability is high and solar energy provides a minimal amount of heating during the winter, hot water is needed year-round and solar energy can provide 40 to 60 percent (see Table 6) of the hot water load on an annual basis in many locations. Unlike the heating load, the hot water load is not directly out of phase with the solar energy availability.
3. Solar water heating is usually accomplished by using an active collector system, and it can be easily retrofitted to most buildings.

For these reasons, solar hot water heating should be of primary concern in initial solar design of buildings.

TABLE 6: ANNUAL PERCENTAGE OF ENERGY FOR HOT WATER PRODUCED BY 150 SQUARE FEET OF STANDARD[1] SOLAR COLLECTORS FOR VARIOUS ALASKAN LOCATIONS.

Location	Latitude °N	Annual Percentage of Solar Hot Water Heating[2] %
Annette	55°2′	52.3
Barrow	71°20′	36.5
Bethel	60°49′	48.4
Big Delta	64°0′	57.9
Bettles	66°55′	53.1
Fairbanks	64°49′	54.0
Gulkana	62°9′	58.3
Homer	59°38′	58.0
Juneau	58°37′	41.3
King Salmon	56°41′	56.1
Kodiak	57°45′	55.7
Matanuska	61°34′	62.6
McGrath	62°58′	49.3
Kotzebue	66°52′	49.6
Nome	64°30′	48.9
Summit	63°39′	51.8
Yakutat	59°31′	40.9

[1] A standard solar collector is assumed to have a heat removal factor ($F'_r T\alpha$) of 0.80, where T is "tau."
[2] Calculated from the f-chart simulations done to support the development of Figures 12-28. Water requirements were assumed to be 80 gallons per day at 140°F. SOLMET solar radiation data were used.

Computer Simulation

The development of sophisticated simulation computer programs has provided the architect and engineer with a convenient way to predict the performance of active and passive solar systems. It is now possible to evaluate various solar design options rapidly and at relatively small expense. This permits the designer to investigate new ideas and to best use existing systems.

Although modeling solar systems is inherently complicated, it is essential that the simulation programs be easily accessible and relatively simple to use. Now that many of the basic computational algorithms have been written and verified, increased attention is being given to making programs more user oriented. The F-Chart computer simulation program by Beckman and Duffie was used to do the solar hot water economics charts in figures 15–31. It is available for PC computers at www.fchart. com/fchart/fchartss.shtml

It should be noted that the results of extensive simulations at universities, government laboratories, and architectural-engineering offices are increasing our knowledge of efficient use of solar energy. Simple correlations and rules of thumb serve as guidelines for the design of cost-effective, energy-conserving solar buildings.

Sizing The Active System By Computer

Conceptually, an active solar system for heating domestic water consists of the following elements (Figure 14): collectors, piping, heat exchanger, storage tank, and auxiliary heater (commonly a standard water heater). There are rules of thumb for sizing solar collectors. In Alaska, they should be used with caution; it is advisable to use a computer simulation program such as F-Chart for sizing (see Beckman et al., 1977). Sizing a system is a complicated process involving the optimization of many different physical and economic factors. In fact, F-Chart uses a set of forty-three different parameters.

Figures 15–31 were developed to evaluate the economic worth of an investment in a solar collector system for a changing set of circumstances. The charts are designed to compare total solar system costs on the basis of the cost per square foot of collector area. This is a common index of cost comparison for active solar collector systems. To ease the comparison, 150 square feet of collector was always used. This is about the optimum area for solar systems heating domestic water in Alaska. The cost of the collectors was then increased in increments of $10 from $10 to $60 per square foot and compared to the cost of backup fuels. Economic worth is measured in the very conservative economic evaluation known as undiscounted payback. In simple terms, this means, "How many years will it be until the cost of the fuel I save equals the investment I've made in solar energy?"

The charts also are based on the following assumptions and F-Chart parameters. Ground reflectivity is varied by month to account for the added performance of tilted collectors due to snow cover in the autumn, winter, and spring. The reflectances are given as fractions of the total incident solar radiation on a surface. They are assumed to be 0.6 for snow cover and 0.2 for dry land, as in the summer.

The assumed storage capacity for these charts is 30 BTU/°F•ft^2, or about 500 gallons. Although this is a large amount of storage, it is not crucial to the cost comparisons. Hot water use is assumed to be 80 gallons per day at 140°F. Backup fuel is assumed to inflate at the rate of 15 percent each year, and the collectors are tilted at an angle from the horizontal equal to the latitude of the site.

Geometry Of Solar Collection In Alaska

A solar collector's performance is somewhat sensitive to the tilt of the collector from the horizontal, as well as its

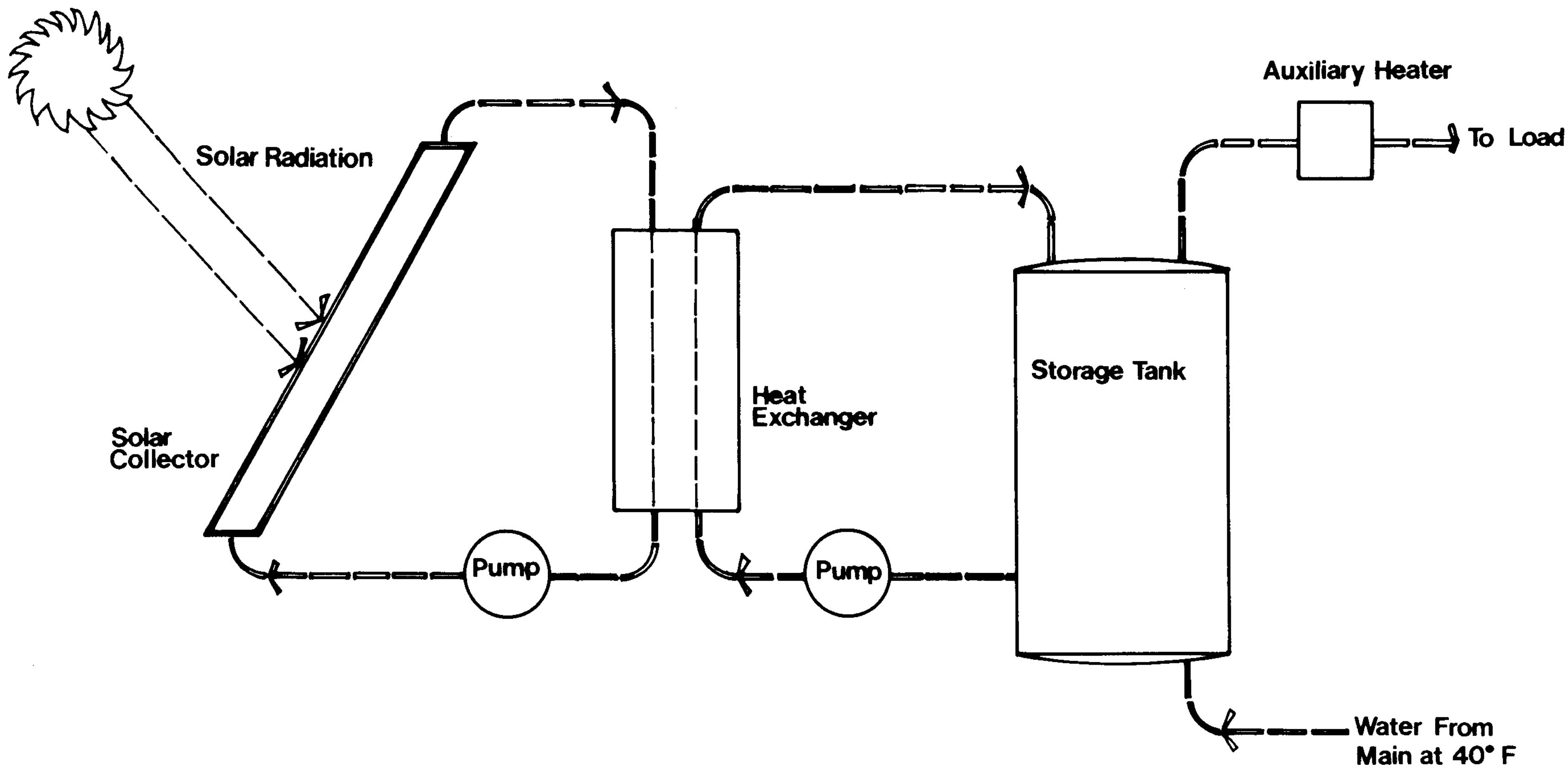

Figure 14. Schematic of a typical active solar domestic water heating system.

TABLE 7: TYPICAL RESULTS OF AN F-CHART COMPUTER SIMULATION FOR AN ACTIVE SOLAR DOMESTIC HOT WATER HEATING SYSTEM IN MATANUSKA, ALASKA.

			Thermal Analysis			
Time	**Percent Solar**	**Incident Solar (MMBTUI**	**Heating Load (MM8TU)**	**Water Load (MMBTU)**	**Degree Days (F-DAY)**	**Ambient Temp (F)**
Jan	18.8	1.47	0	1.90	1645	12.2
Feb	39.9	2.02	0	1.72	1285	19.4
Mar	88.5	4.72	0	1.90	1240	26.6
Apr	82.9	4.17	0	1.84	859	35.6
May	80.3	4.05	0	1.90	558	46.4
Jun	77.2	3.66	0	1.84	302	53.6
Jul	71.3	3.40	0	1.90	232	57.2
Aug	60.2	2.85	0	1.90	304	53.6
Sep	43.3	2.08	0	1.84	518	46.4
Oct	26.3	1.58	0	1.90	947	33.8
Nov	8.7	1.01	0	1.84	1328	21.2
Dec	0	0.55	0	1.90	1627	14.0
Yr	49.8	31.55	0	22.41	10847	

Economic Analysis

Optimized collector area = 87 FT2
Initial cost of solar system = $3,175
The annual mortgage payment for 20 years = $324
The rate of return on the solar investment (%) = 8.8
Years until undiscounted fuel savings = investment 13
Years until undiscounted solar savings = mortgage principal 17
Undiscounted cumulative solar savings = $3,176
Present worth of yearly total costs with solar = $7,677
Present worth of yearly total costs without solar = $7,799
Present worth of cumulative solar savings = $122

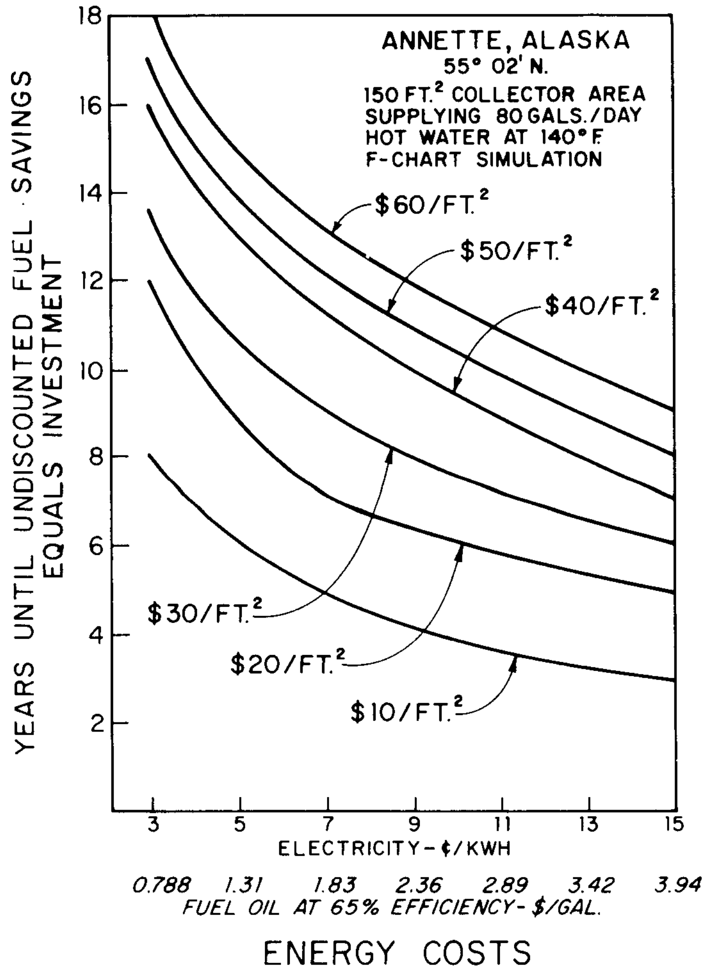

Figure 15. Payback period for solar domestic water heating system in Annette, Alaska.

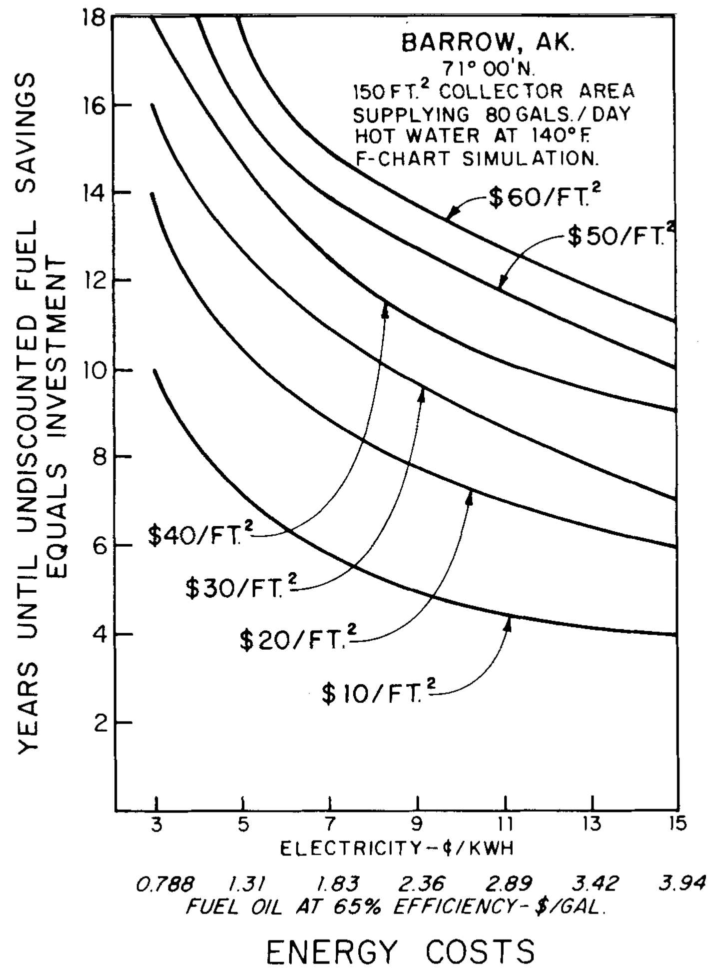

Figure 16. Payback period for solar domestic water heating system in Barrow, Alaska.

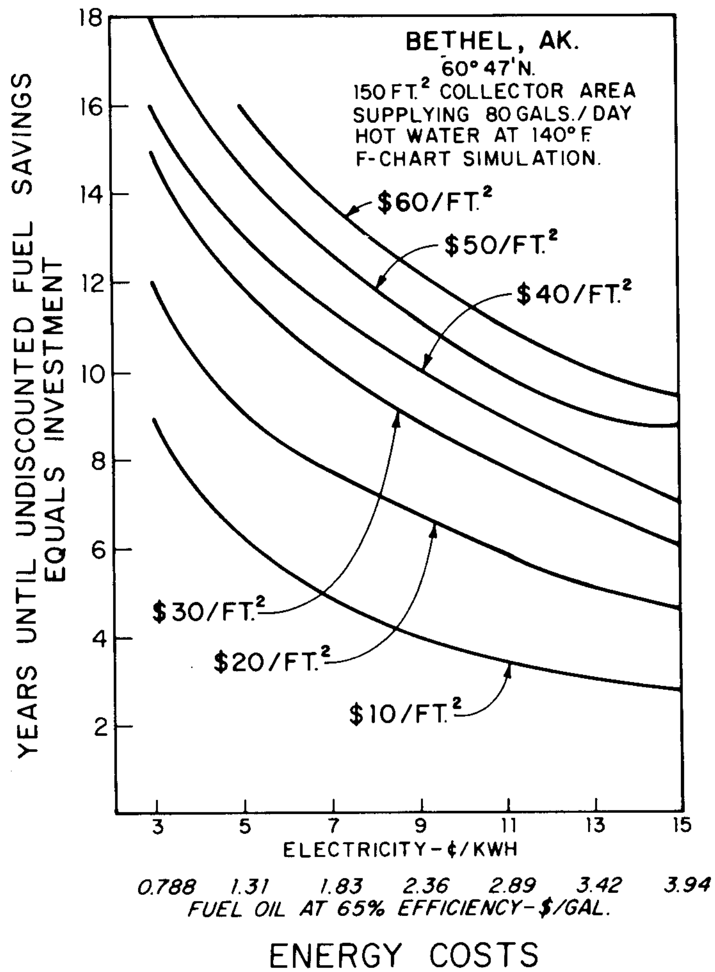

Figure 17. Payback period for solar domestic water heating system in Bethel, Alaska.

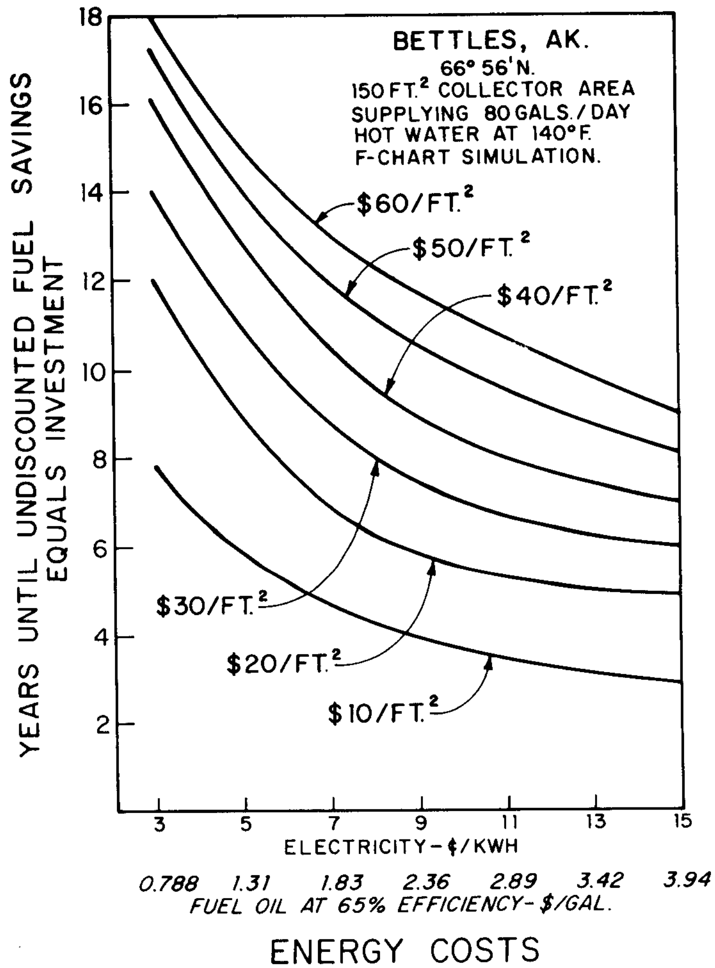

Figure 18. Payback period for solar domestic water heating system in Bettles, Alaska.

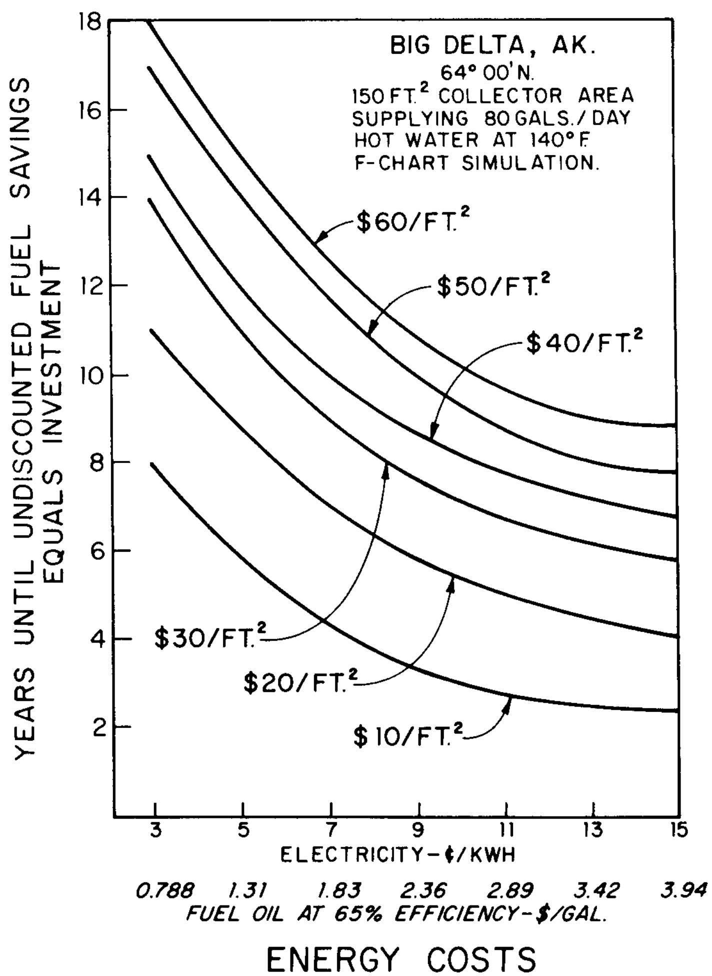

Figure 19. Payback period for solar domestic water heating system in Big Delta, Alaska.

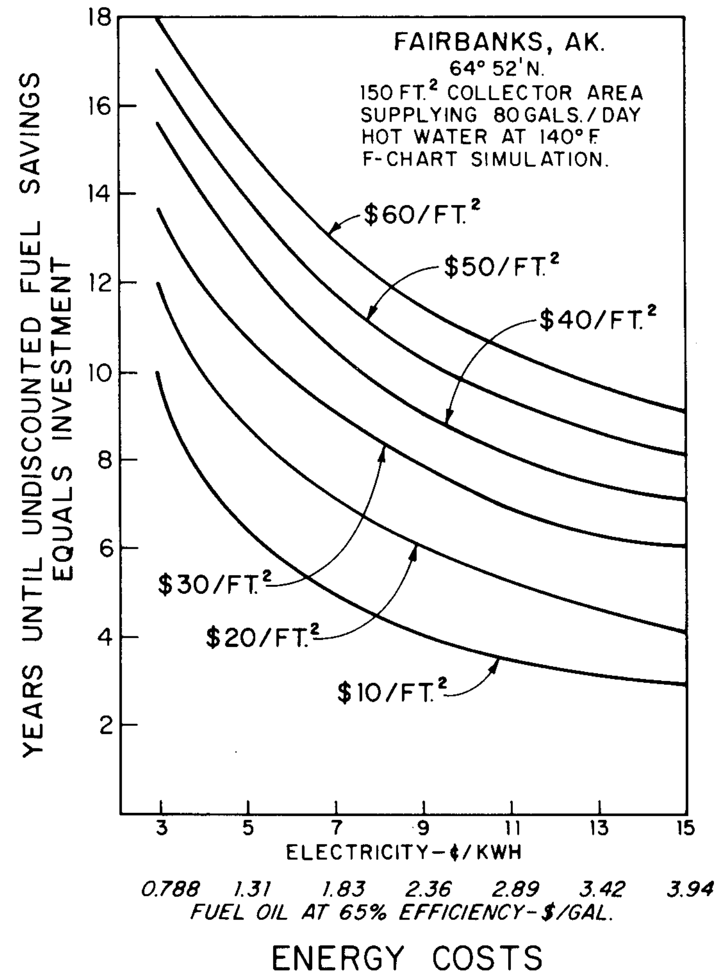

Figure 20. Payback period for solar domestic water heating system in Fairbanks, Alaska.

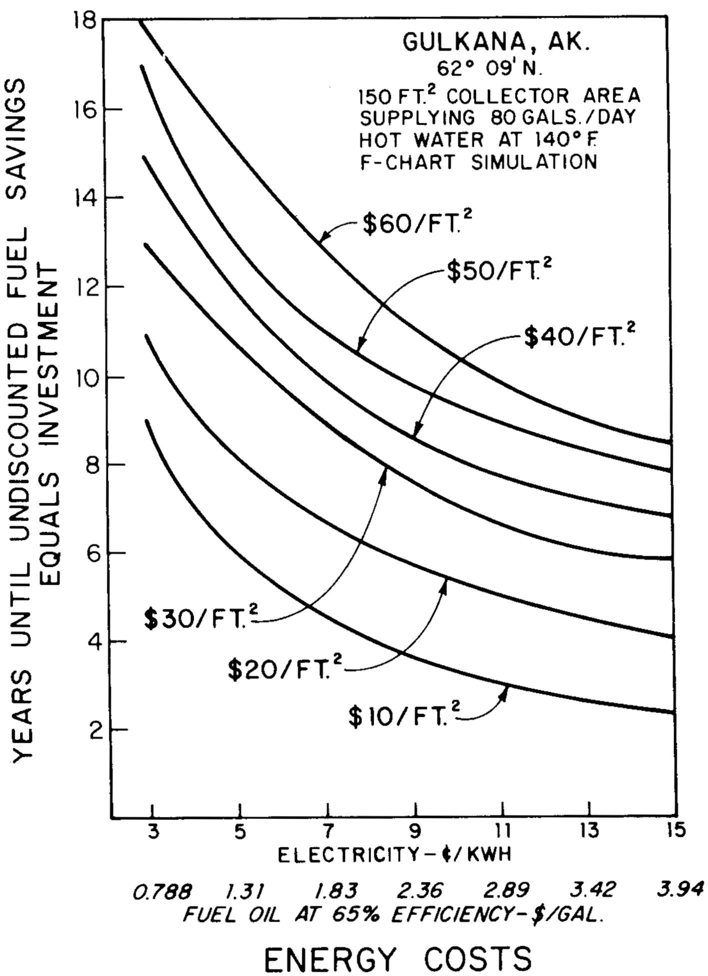

Figure 21. Payback period for solar domestic water heating system in Gulkana, Alaska.

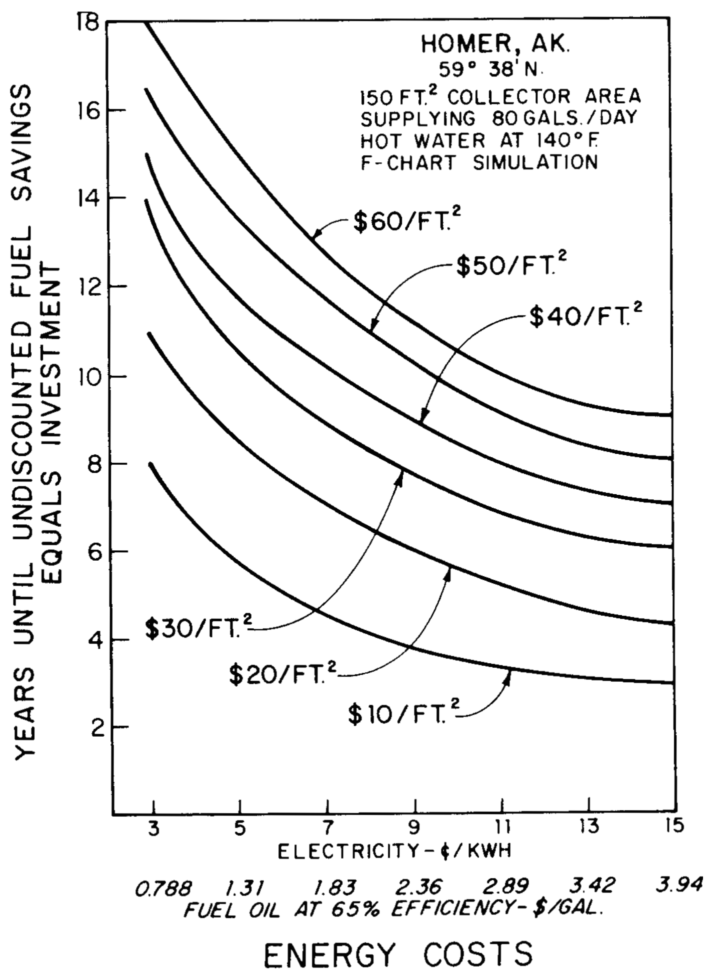

Figure 22. Payback period for solar domestic water heating system in Homer, Alaska.

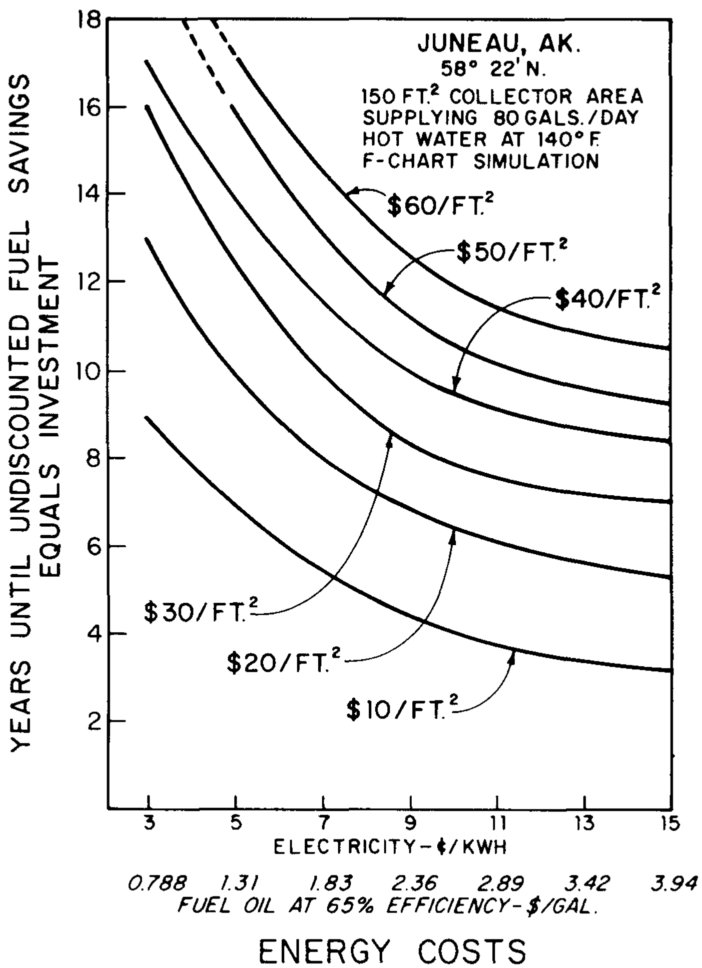

Figure 23. Payback period for solar domestic water heating system in Juneau, Alaska.

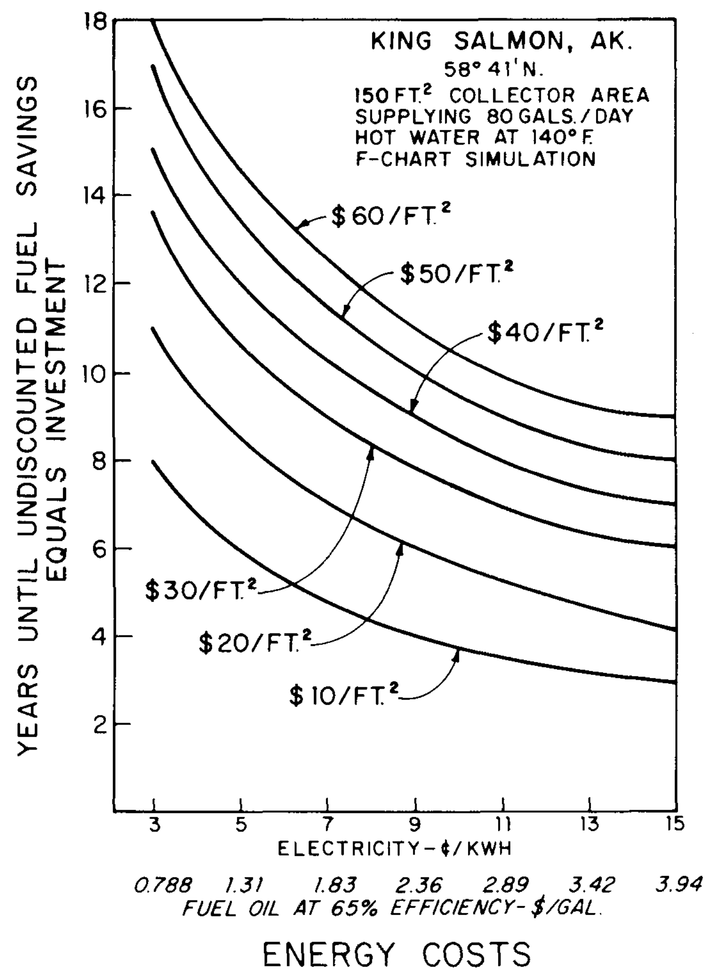

Figure 24. Payback period for solar domestic water heating system in King Salmon, Alaska.

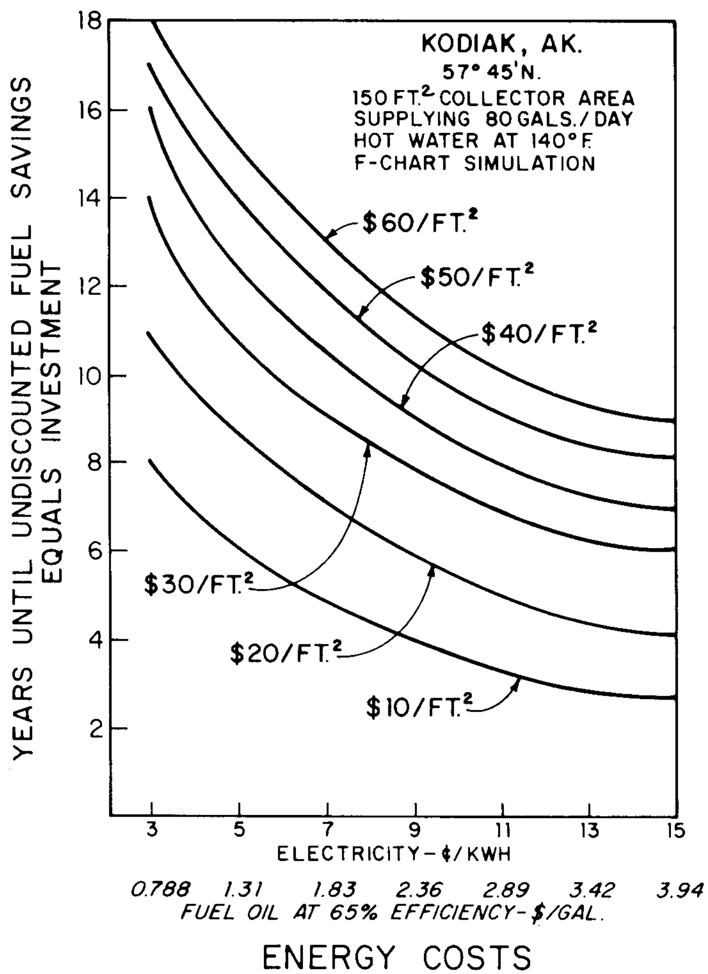

Figure 25. Payback period for solar domestic water heating system in Kodiak, Alaska.

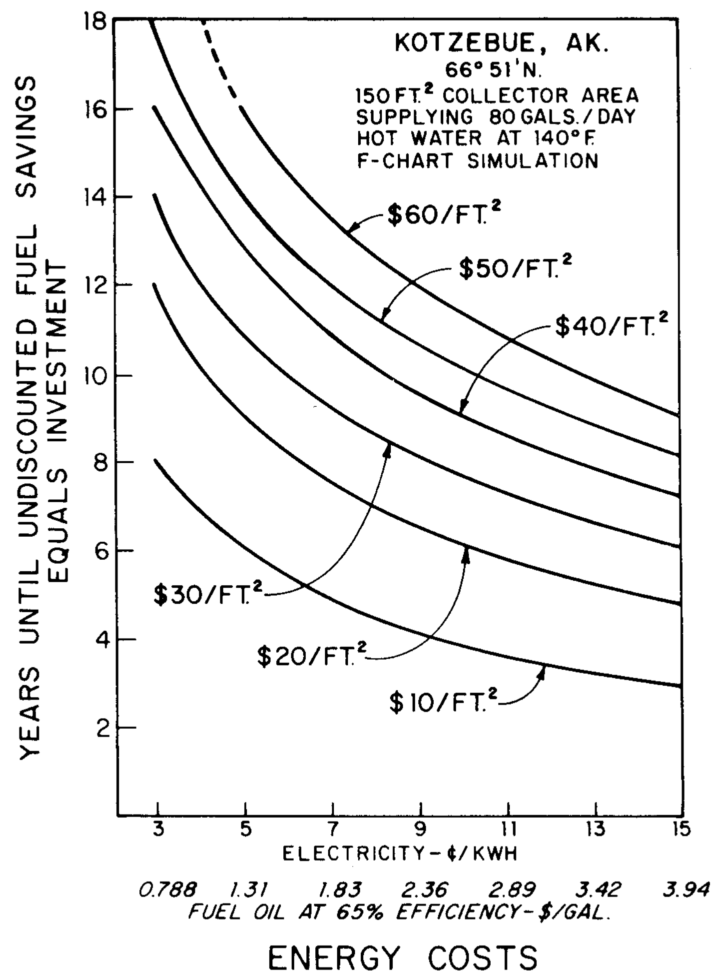

Figure 26. Payback period for solar domestic water heating system in Kotzebue, Alaska.

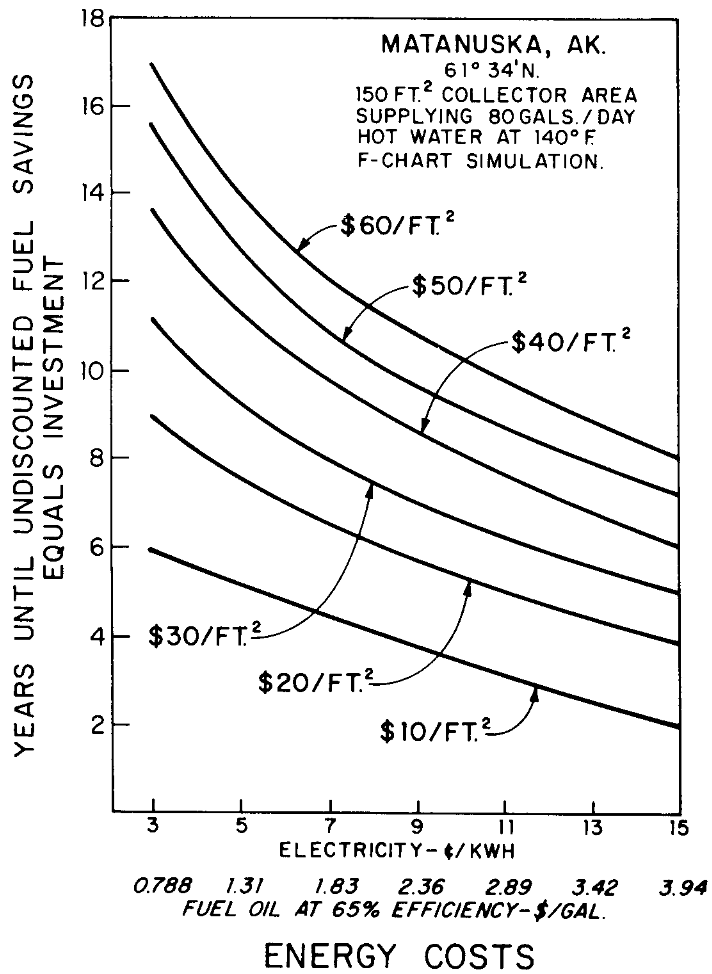

Figure 27. Payback period for solar domestic water heating system in Matanuska, Alaska.

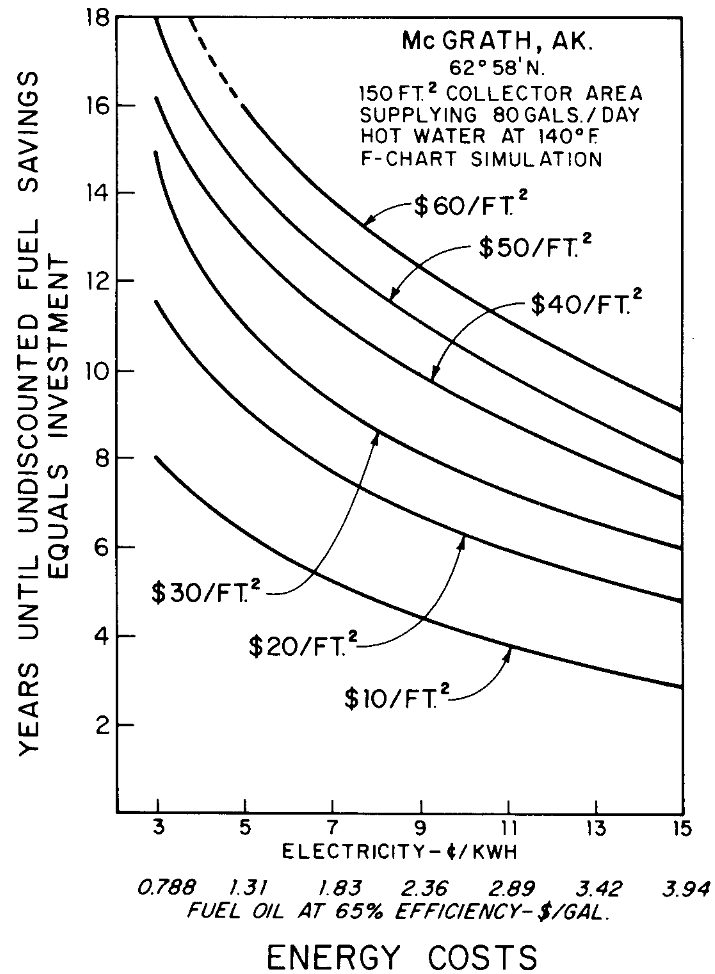

Figure 28. Payback period for solar domestic water heating system in McGrath, Alaska.

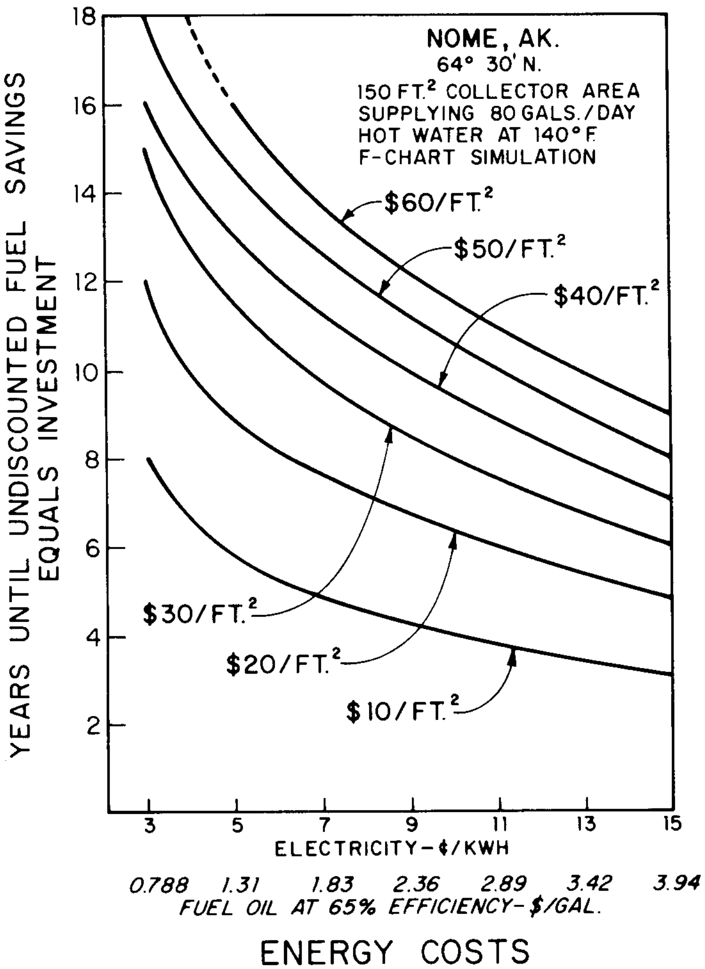

Figure 29. Payback period for solar domestic water heating system in Nome, Alaska.

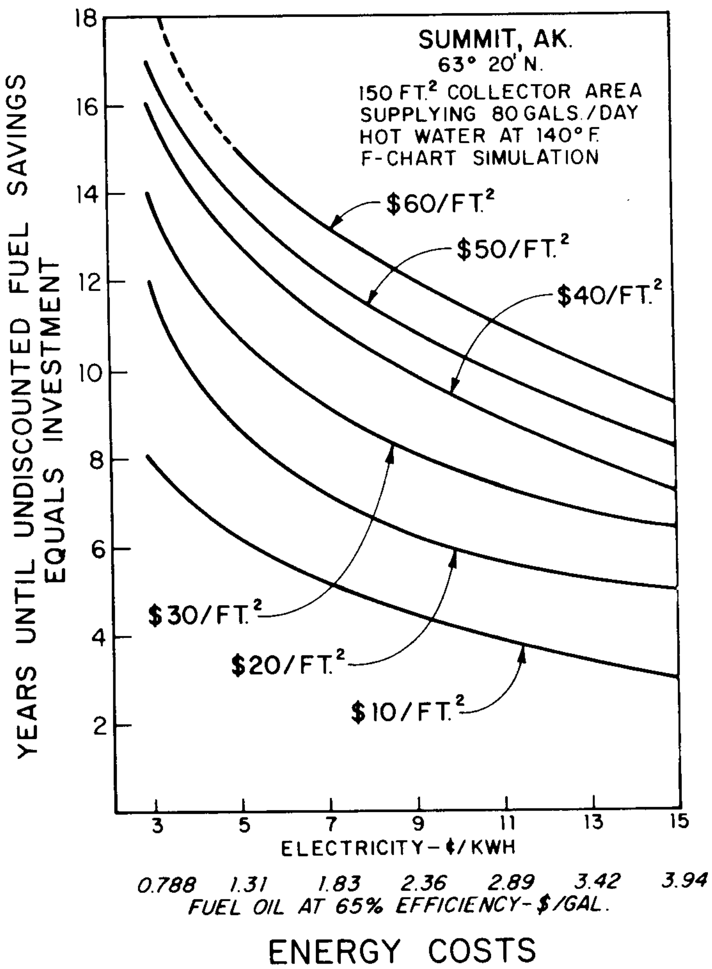

Figure 30. Payback period for solar domestic water heating system in Summit, Alaska.

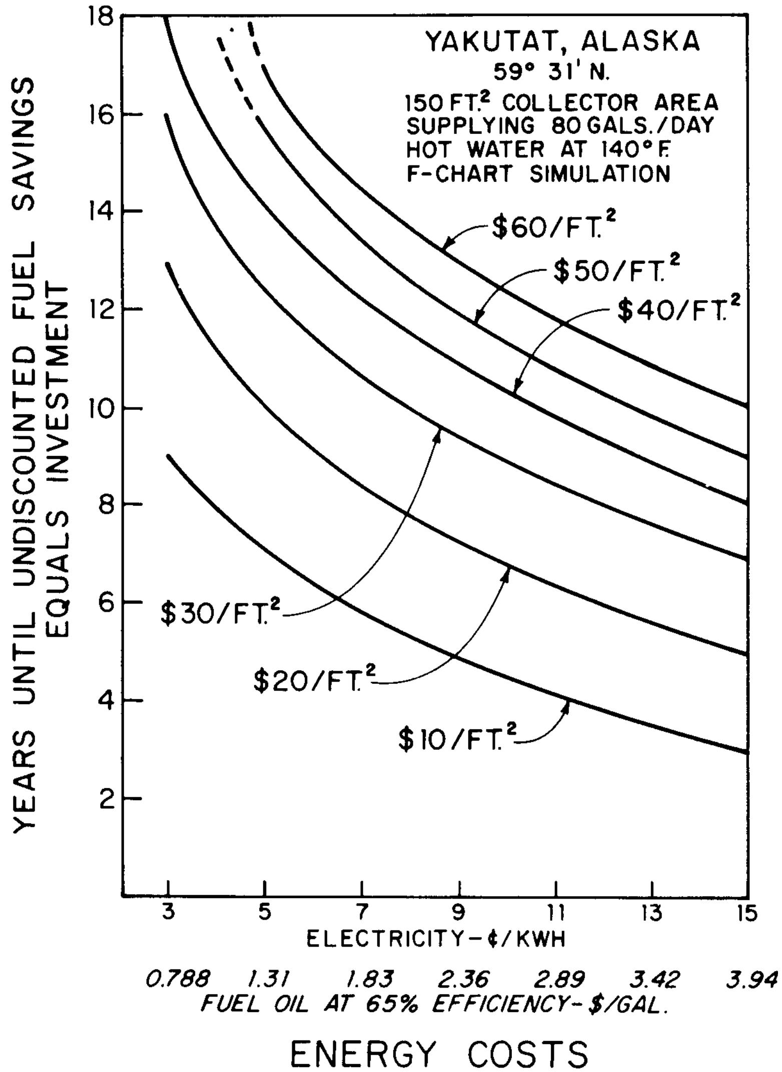

Figure 31. Payback period for solar domestic water heating system in Yakutat, Alaska.

azimuthal (east or west of south) orientation. Figures 32 and 33 indicate the important angles to consider in active solar designs. Collector tilt in Alaska depends upon the desired application of captured heat. Space heating needs peak in the winter, so a collector tilt greater than the latitude would provide optimum radiation capture during the peak heating season. Domestic hot water needs are relatively constant throughout the year, so a collector tilt less than the latitude would be more efficient on an annual basis. A collector tilt equal to the latitude optimizes solar collection during the equinox periods of the year, March and September. In the Lower 48, it is often recommended to tilt the angle of the collectors 10 degrees or more greater than the latitude of the site to optimize energy capture during the winter. This is a bad strategy in Alaska because solar radiation is so limited in the winter. Such a strategy would reduce the amount of solar energy captured on a yearly basis.

Table 8 shows the effect of collector tilt on collector performance for two cases (solar water heating, and solar space and water heating combined) for the examples of Matanuska and Fairbanks. The examples show that collector tilt is **not** crucial in the performance of collectors, but that an optimum tilt of collectors for hot water heating is between 10 and 20° less than the latitude of the site in

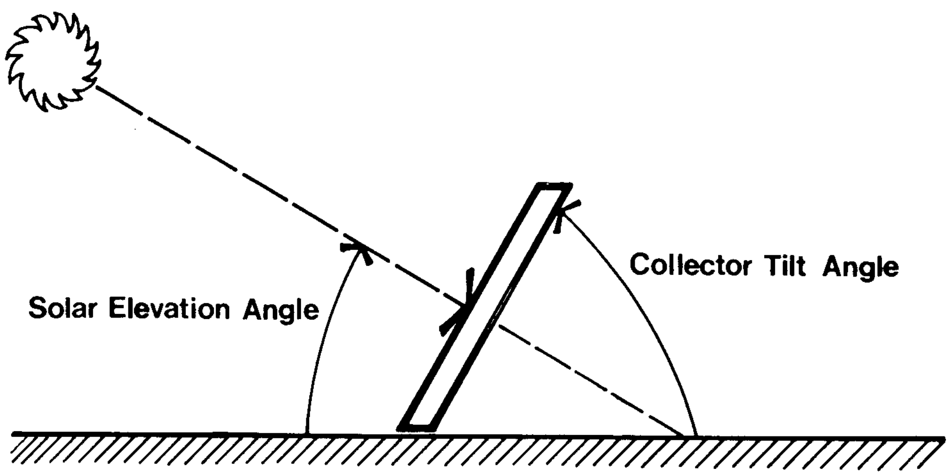

Figure 32. Collector tilt angle in relation to the ground surface and the solar elevation angle. Collector tilt is optimum when the sum of the collector tilt angle and the solar elevation angle (at noon) equals 90°, indicating the maximum solar intensity possible at noon on the collector surface. This optimum tilt changes daily, so an annual optimum tilt must be selected if collectors are not movable.

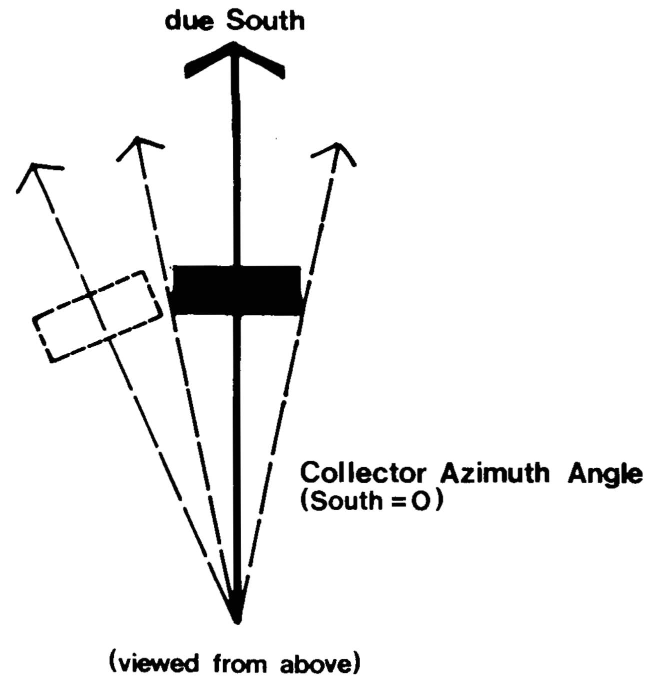

Figure 33. An illustration of what is meant by the azimuth of a collector. Any nonsouth orientation will reduce the total daily solar radiation gain in proportion to the azimuth angle. The largest theoretical sum of total daily radiation will fall on a surface that faces due south.

Alaska. For space heating and hot water heating combined, the optimum tilt is approximately equal to the latitude of the site.

Azimuth, the angular placement of a collector east or west of south, is also **not** crucial to within 30° east or west of due south. Even an azimuthal orientation of 50° west (or east) of due south decreases the total amount of the solar percentage of energy by only 8.5 percent.

These facts imply much more opportunity for architectural and siting variation than is normally assumed. The actual orientation of a collector can have a tilt from 20 to 90° without decreasing the useful energy obtained from it by more than 13 percent. Azimuthal orientations can vary by as much as 50° east or west of south without changing the total useful solar gain of a collector by more than 10 percent. (See Table 9.)

Because of Alaska's high-latitude solar geometry and the presence of snow on roofs and tilted surfaces for much of the winter season, solar collectors and photovoltaic panels are perhaps best mounted on a vertical surface (like a south wall). Although not optimum for maximum collection of solar radiation, this allows two other very important conditions to be met:

1. Snow, dirt, and dust will not accumulate on collector surfaces, and maintenance will be easier. A wall mount avoids the more dangerous ascent to the roof as well, when maintenance or cleaning is required.
2. A vertical collector surface dramatically enhances the collection of reflected solar radiation off the seasonal snow cover. This is especially so in the springtime, between February and April, a maximum period of solar availability and a time when solar heat is needed.

TABLE 8: DAILY HOT WATER USAGE (140°F) FOR SOLAR SYSTEM DESIGN

Category	One and Two Family Units and Apts. up to 20 Units[1]					Apts. of 20-200 Units	Apts. of Over 200 Units[2]
Number of People	2	3	4	5	6	—	—
Number of Bedrooms	1	2	3	4	5		
Hot Water/Unit (gal/day)	40	55	70	85	100	40	35

[1]Assumes 20 gallons per person for first 2 people and 15 gallons per person for additional family members.
[2]From Werden and Spielvogel (1969).

Shading And Topography

One of the naturally occurring benefits of deciduous trees (trees that lose their leaves annually) is that their shading during the warm period of the year disappears as the heating season begins, and shade only begins again as heating requirements end in the spring. Ideally, an active system for space heating could be located in a stand of deciduous trees without a great decrease in its efficiency. Trees and shading from other buildings should be carefully reviewed on site before a final collector design is chosen, however. It may be necessary to negotiate or purchase a solar easement from neighboring properties to ensure "solar access"—the guarantee that nothing will be constructed or allowed to grow that will shade your solar collectors.

More on shading will be discussed in the section of the manual describing direct gain in passive solar applications.

TABLE 9: EFFECT OF TILT AND AZIMUTH ANGLE ON SOLAR COLLECTOR PERFORMANCE.[1]											
Fairbanks, Alaska 64°49'N						Matanuska, Alaska 61°34'N					
Water Heating Only[2]			Space and Water Heating[3]			Water Heating Only[2]			Space and Water Heating[3]		
Azimuth (degrees)	Tilt (degrees)	Annual Solar Contribution %	Azimuth (degrees)	Tilt (degrees)	Annual Solar Contribution %	Azimuth (degrees)	Tilt (degrees)	Annual Solar Contribution %	Azimuth (degrees)	Tilt (degrees)	Annual Solar Contribution %
0	64	54	0	64	27	0	61	63	0	61	41
0	54	55	0	74	26	0	51	63	0	71	40
0	44	54	0	84	24	0	41	62	0	81	38
0	34	53	0	89	23	0	31	59	0	89	36
0	24	51	0	54	27	0	21	56	0	51	41
0	0	44	0	44	27	0	0	47	0	41	39
10	64	54	10	64	26	10	61	63	10	61	40
20	64	54	20	64	26	20	61	62	20	61	40
30	64	53	30	64	26	30	61	61	30	61	39
40	64	52	40	64	25	40	61	60	40	61	38
50	64	51	50	64	25	50	61	58	50	61	36
40	44	53	40	44	25	40	41	59	40	41	37

[1] F-chart computer simulations were used to develop this table. Collectors were not at tilts greater than latitude for water heating because smaller angles are more efficient on an annual basis. However, nearly vertical tilts are optimum for space heating since they maximize winter capture of solar energy.

[2] 150 ft^2 collector area.

[3] 400 ft^2 collector area.

Snow Cover Effects

A positive factor for solar heating in Alaska (a plus for both active and passive designs) is the seasonal snow cover. As can be seen from Figure 34, new snow has a reflectivity (also called albedo) of 70 to 80 percent. This is four times the reflectivity of normal ground cover. In effect, this snow acts as a very efficient mirror, reflecting additional radiation onto the collector. Anderson (1976) states that snow cover can enhance the collection of solar energy from 15 to 30 percent. This has been solidly confirmed in Alaska, even for years that are much cloudier than normal (Seifert, 1983).

Sun Path Diagrams

It is possible to predict the position of the sun at any time (Figures 35 to 59). The path and the position are both a result of the latitude of the site. A sun path diagram is a graphic representation of the path of the sun in the sky for virtually any time of the year. This type of sun path diagram is useful for architectural insights, since a horizon can be sketched onto it to indicate solar obstructions. This is accomplished by sketching in obstacles on the horizon in their true angular perspective. A hand level can be used to get the angular elevations of obstacles. Figure 34 shows an example of a horizon sketched onto a sun path diagram.

Sketching the horizon onto the chart enables the prospective solar user to identify the major obstructions that will shade the collector from the sun. In the example (Figure 35), the trees are the major obstruction. Identifying such obstructions by location can also indicate how much sun is actually blocked by the obstruction. Let us examine the situation in March. Using the March 21 sun path we can see what happens during the day. Beyond 74° east of south, the sun is blocked by the hills to the southeast of the site, so sunrise is delayed until the sun clears the hills. This delay is 1 hour 20 minutes on March 21. From 7:20 a.m. until 1:20 p.m., the sun is unobstructed. The trees to the southwest of the site obstruct the sun during the entire afternoon; the site gets virtually no direct afternoon sun after 1:20 p.m.

This can be quantified by checking the solar position and hourly radiation chart in Appendix C. Using the chart for 64°N, the amount of solar radiation on a 64° tilted surface for March 21 can be determined for each hour. The hours of 2, 3, 4, and 5 p.m. receive 229, 172, 102, and 29 BTU/ft^2 respectively. This is a total of 534 BTU/ft^2. Since the hourly radiation chart also gives us the amount of radiation for the whole day, we can determine the percent of solar energy lost by obstructions. Thus 534 ÷1870 = 28.5 percent of the day's radiation is lost, a substantial amount.

This suggests the need to do whatever one could to remove significant obstructions. Moving the neighboring house is not practical, but the trees could be cut. If the trees have high aesthetic or privacy value for the property, you may wish to change the azimuth of the collector eastward (or the azimuth of the structure if using a passive solar design) to take greater advantage of the morning sun. Increasing the size of collection area is also an option, and the increase should correspond to the percentage of blocked solar gain (about 28 percent in this case).

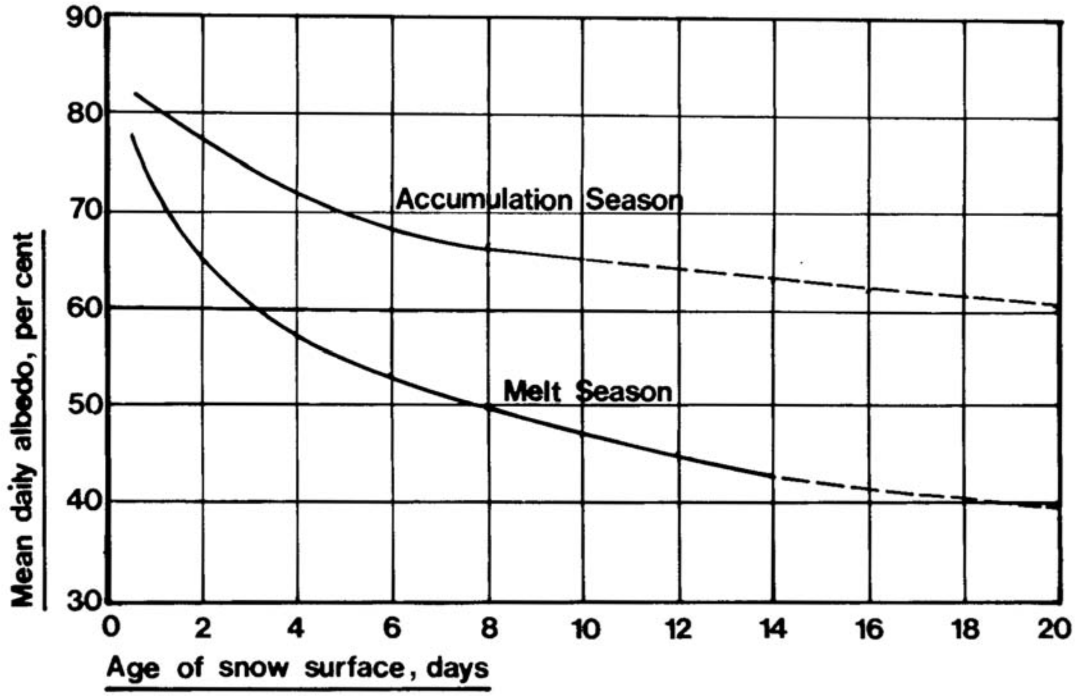

Figure 34. The relationship between the age of snow (in days) and its albedo (reflectance), expressed as a percentage of incident solar radiation, for both the accumulation (early to midwinter) and melt seasons.

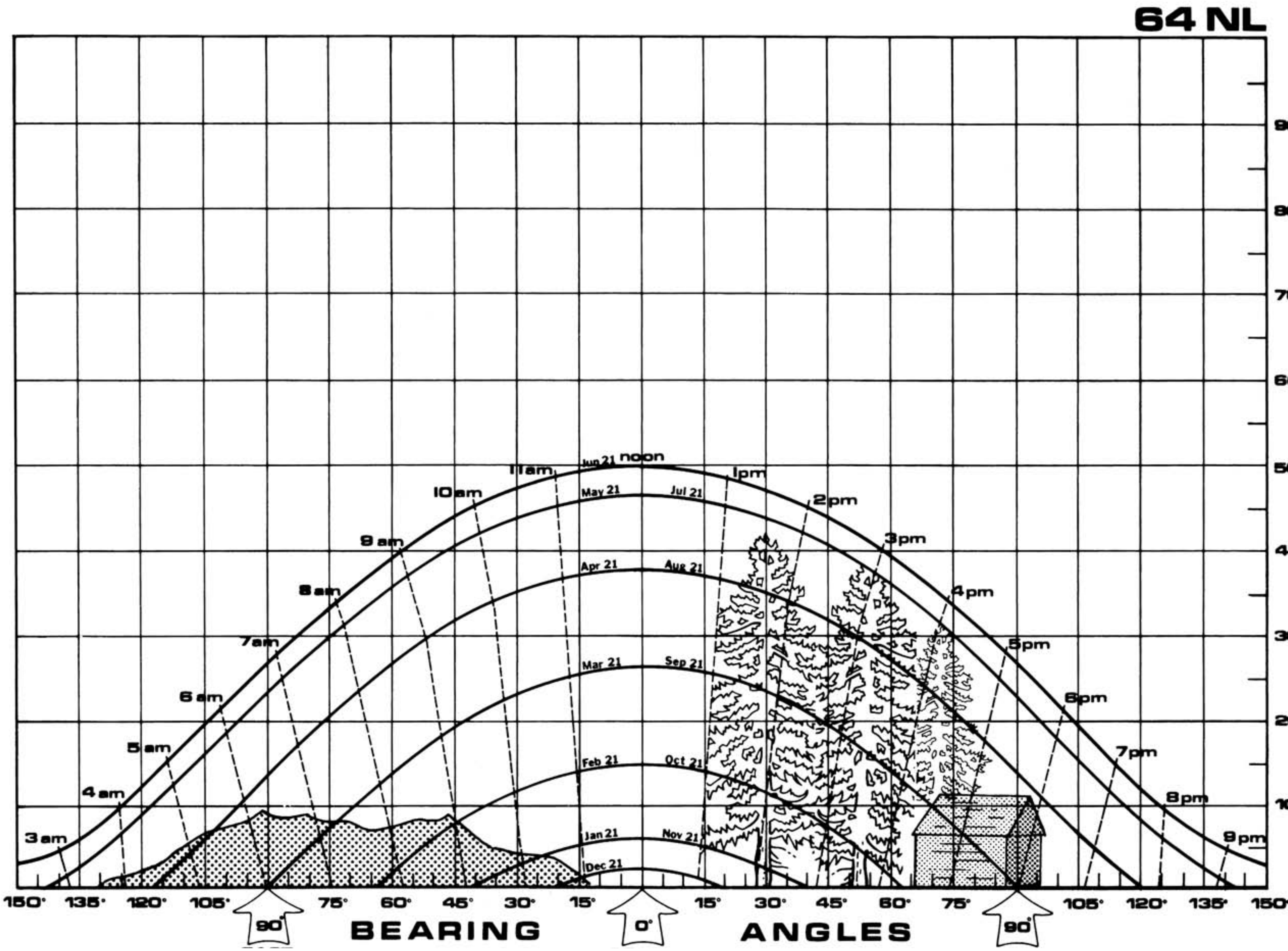

Figure 35. Example of horizon sketched on a sun path diagram.

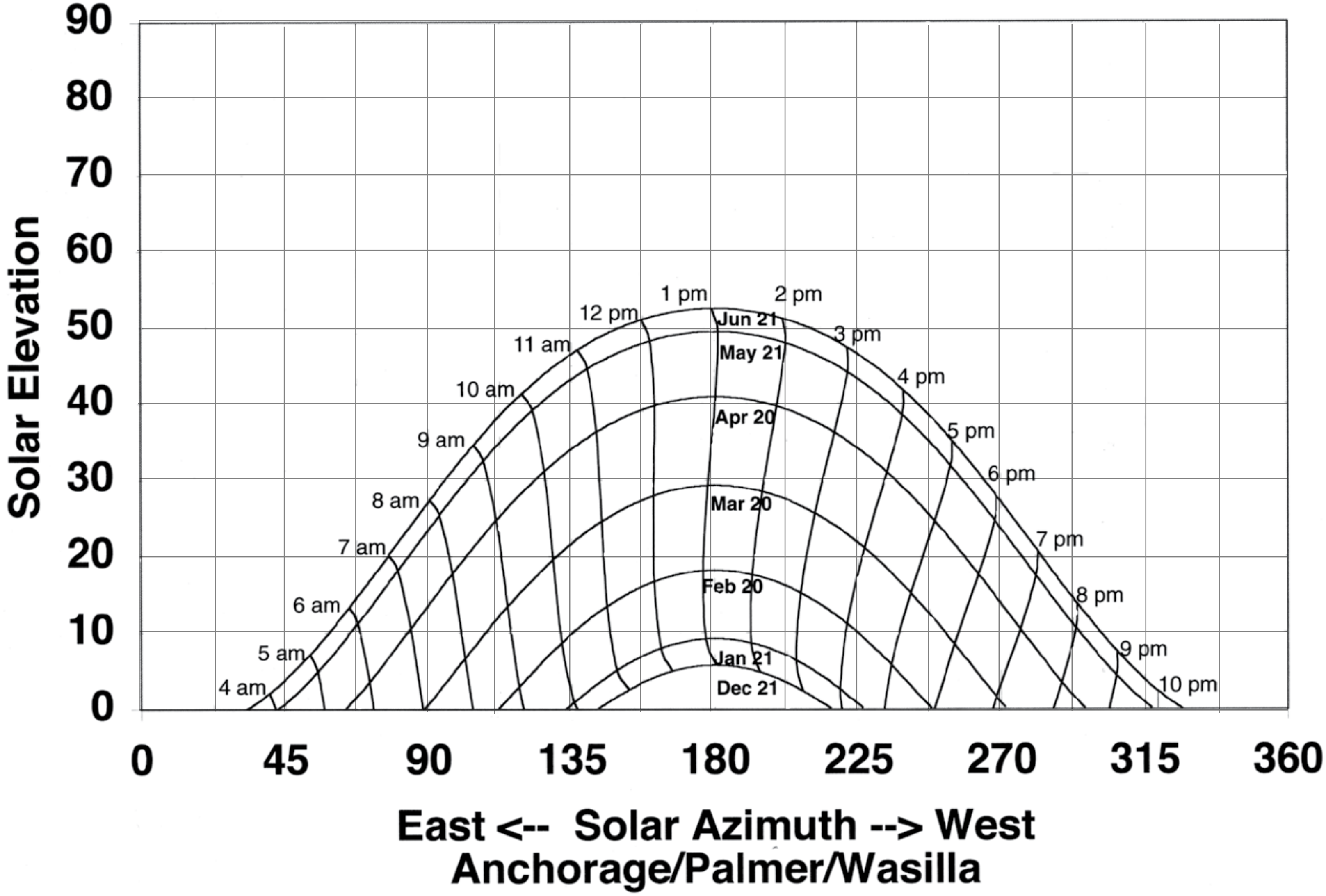

Figure 36. Sun path diagram for Anchorage/Palmer/Wasilla, Alaska. Latitude: 61 N; Longitude: 150 W.

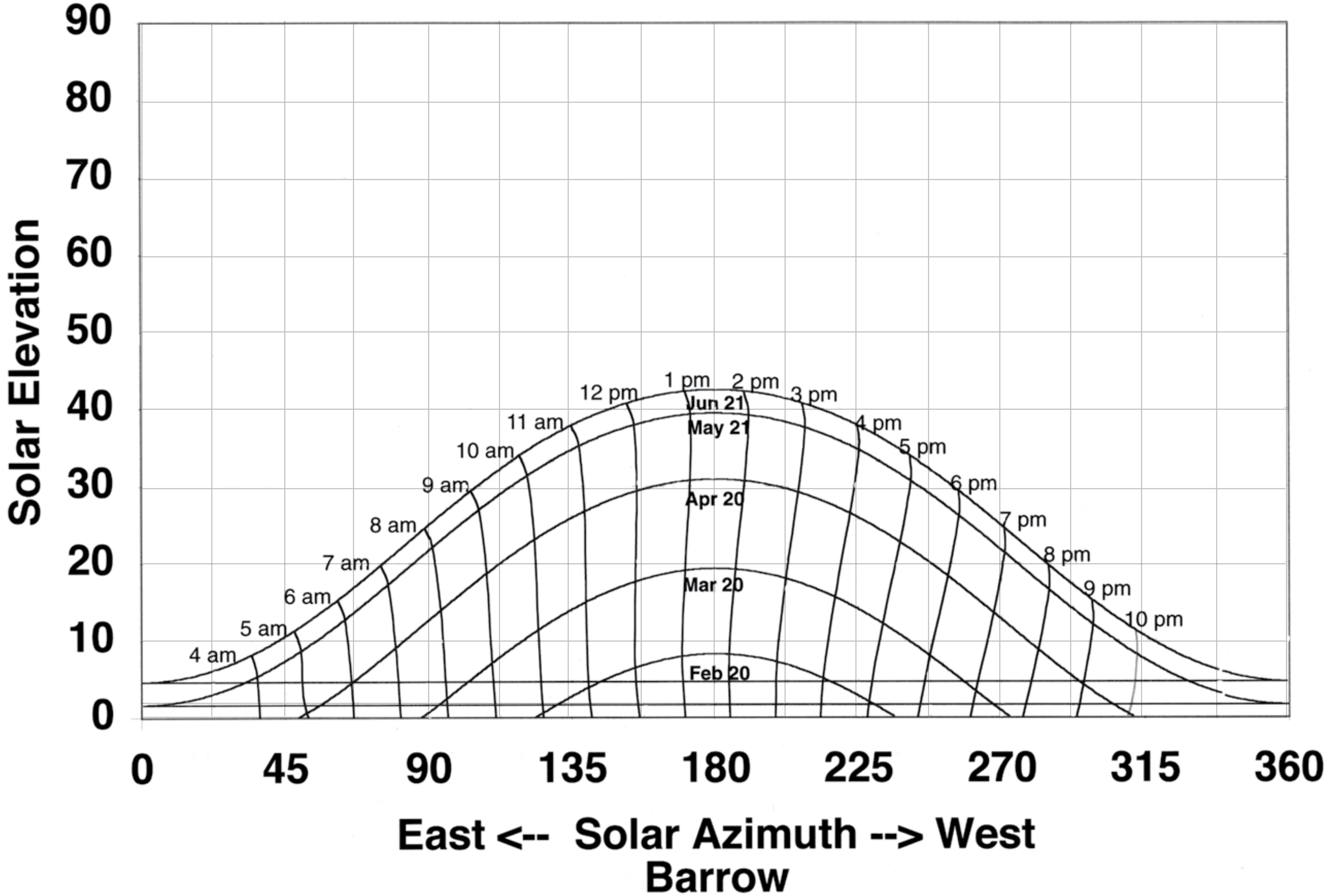

Figure 37. Sun path diagram for Barrow, Alaska. Latitude: 71 N; Longitude: 157 W.

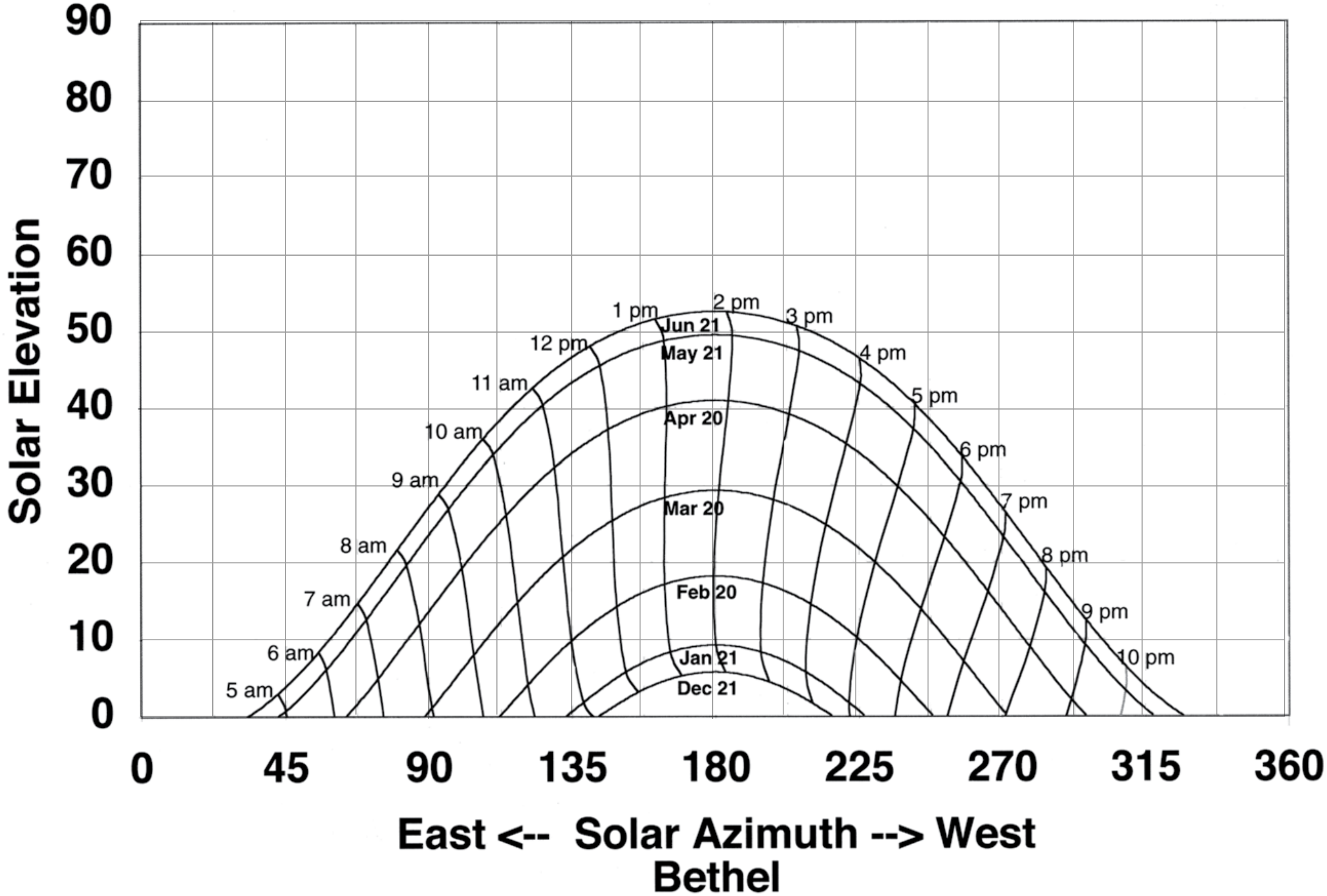

Figure 38. Sun path diagram for Bethel, Alaska. Latitude: 61 N; Longitude: 162 W.

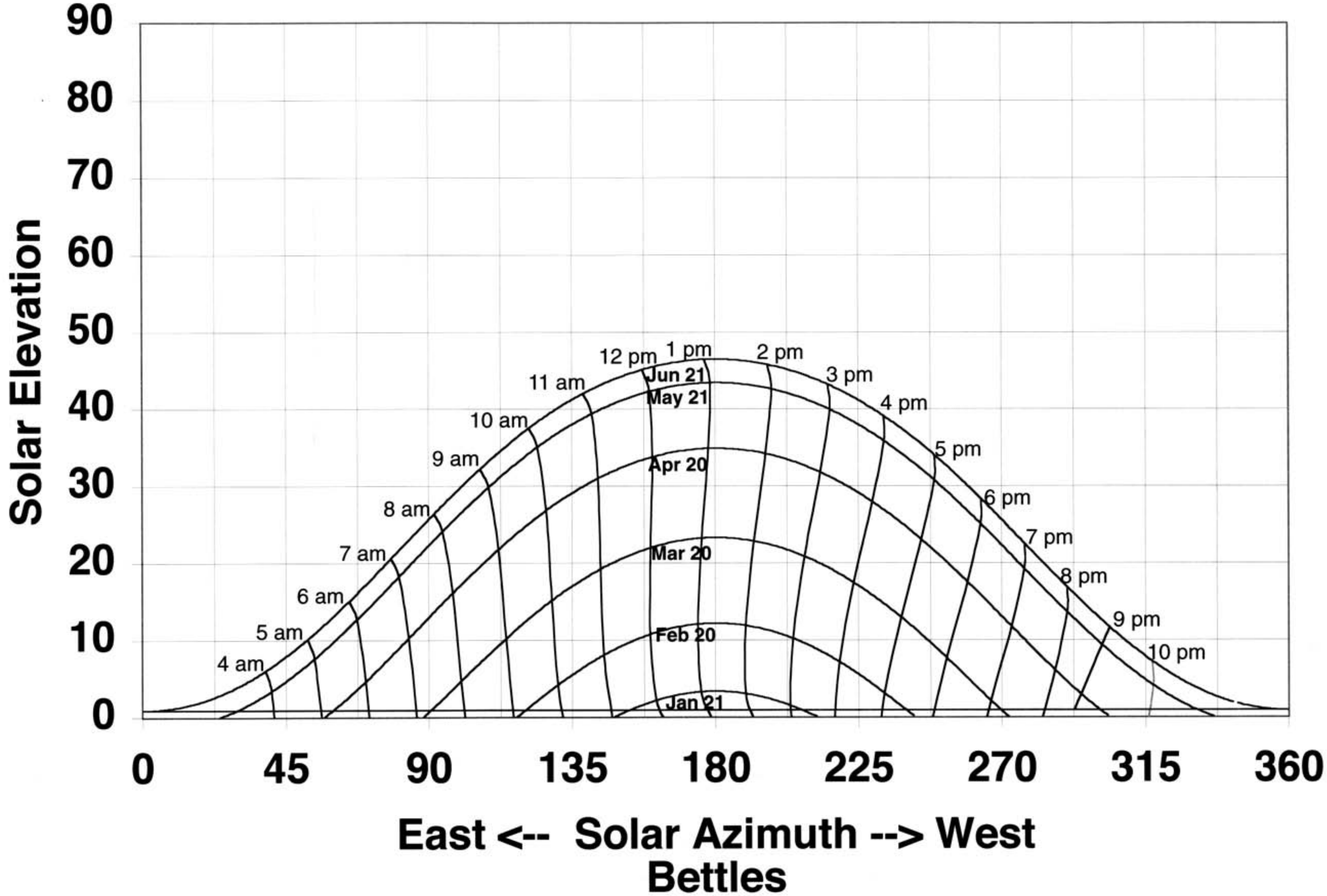

Figure 39. Sun path diagram for Bettles, Alaska. Latitude: 67 N; Longitude: 152 W.

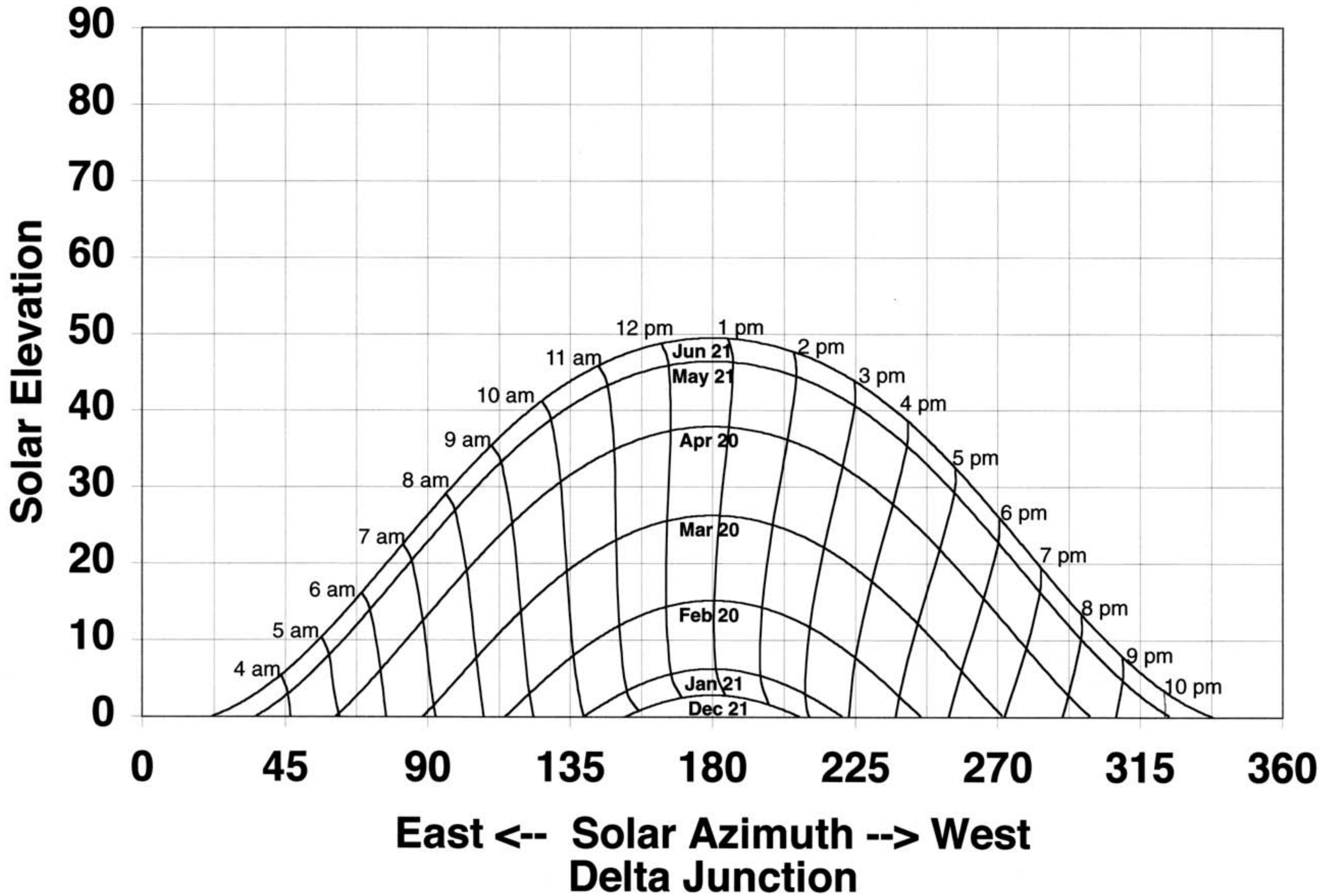

Figure 40. Sun path diagram for Delta Junction, Alaska. Latitude: 64 N; Longitude: 146 W.

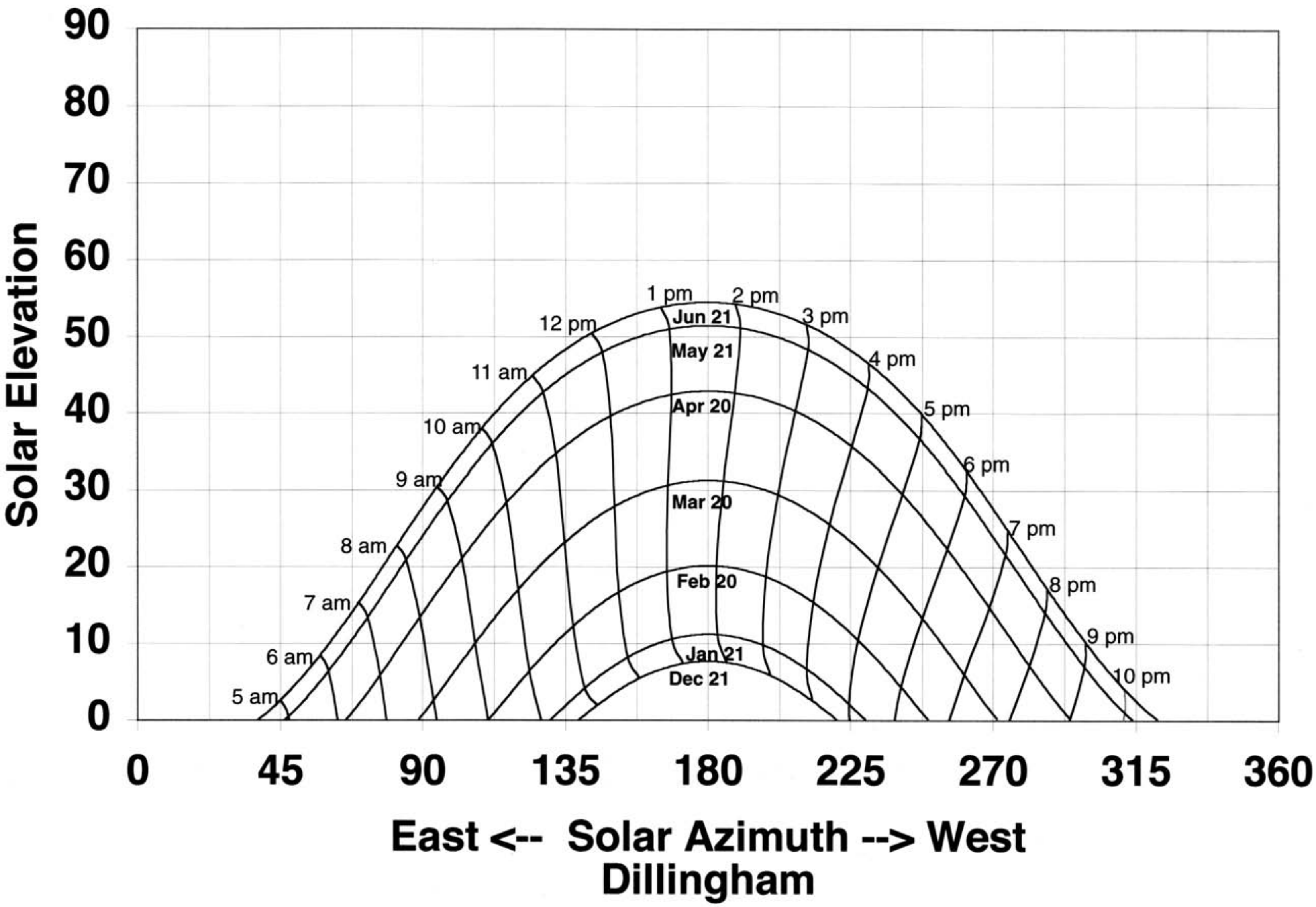

Figure 41. Sun path diagram for Dillingham, Alaska. Latitude: 59 N; Longitude: 159 W.

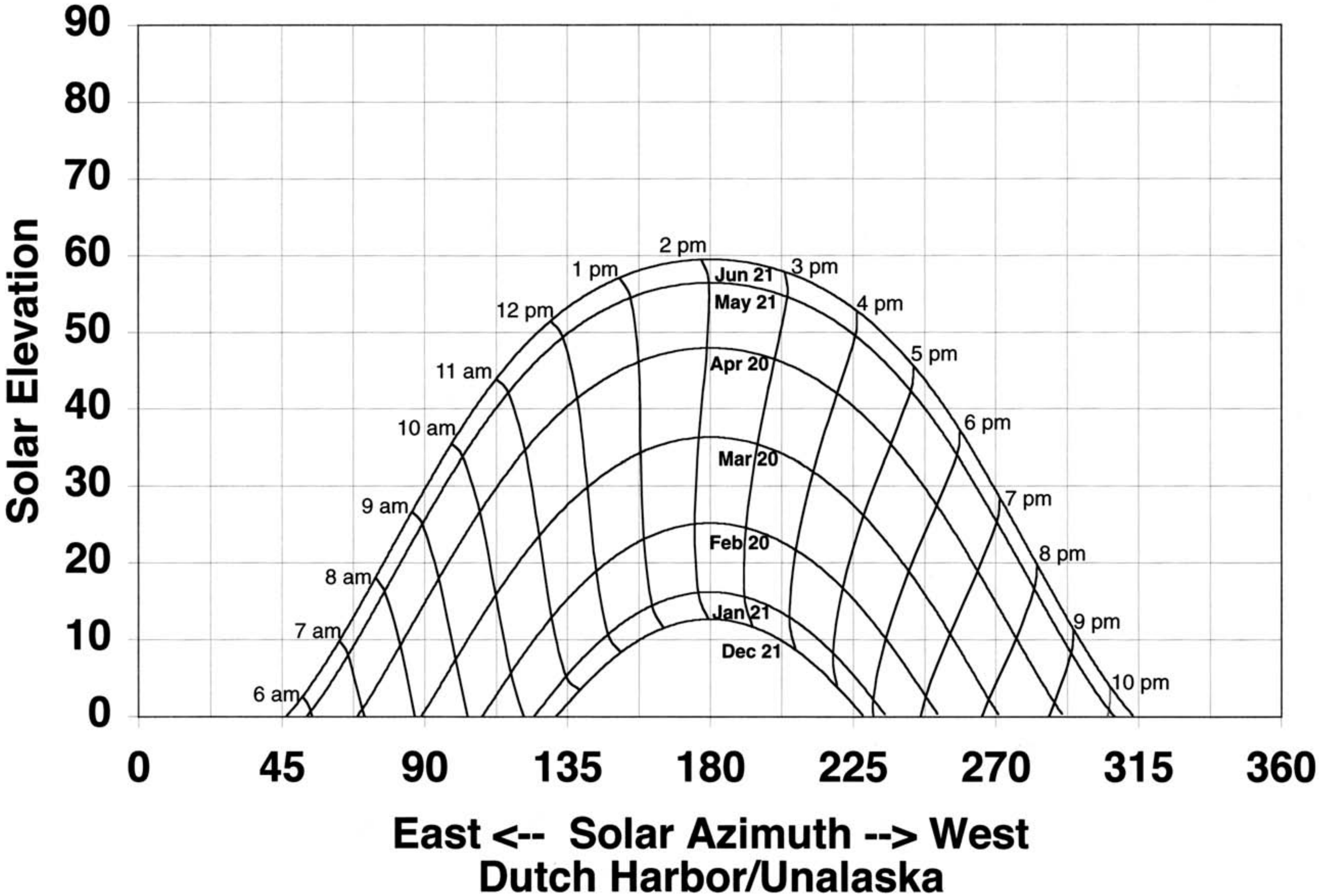

Figure 42. Sun path diagram for Dutch Harbor/Unalaska, Alaska. Latitude: 54 N; Longitude: 166 W.

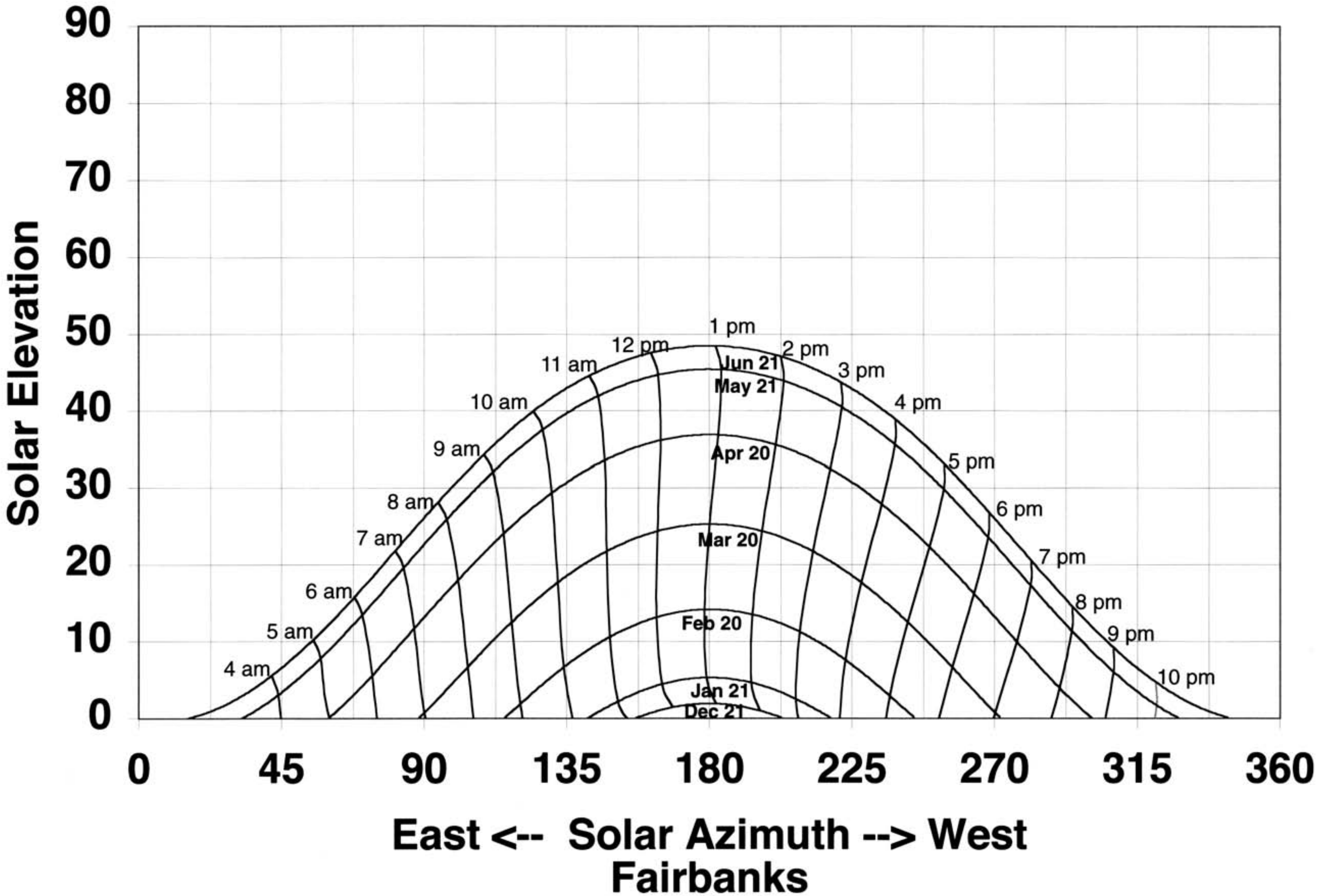

Figure 43. Sun path diagram for Fairbanks, Alaska. Latitude: 65 N; Longitude: 148 W.

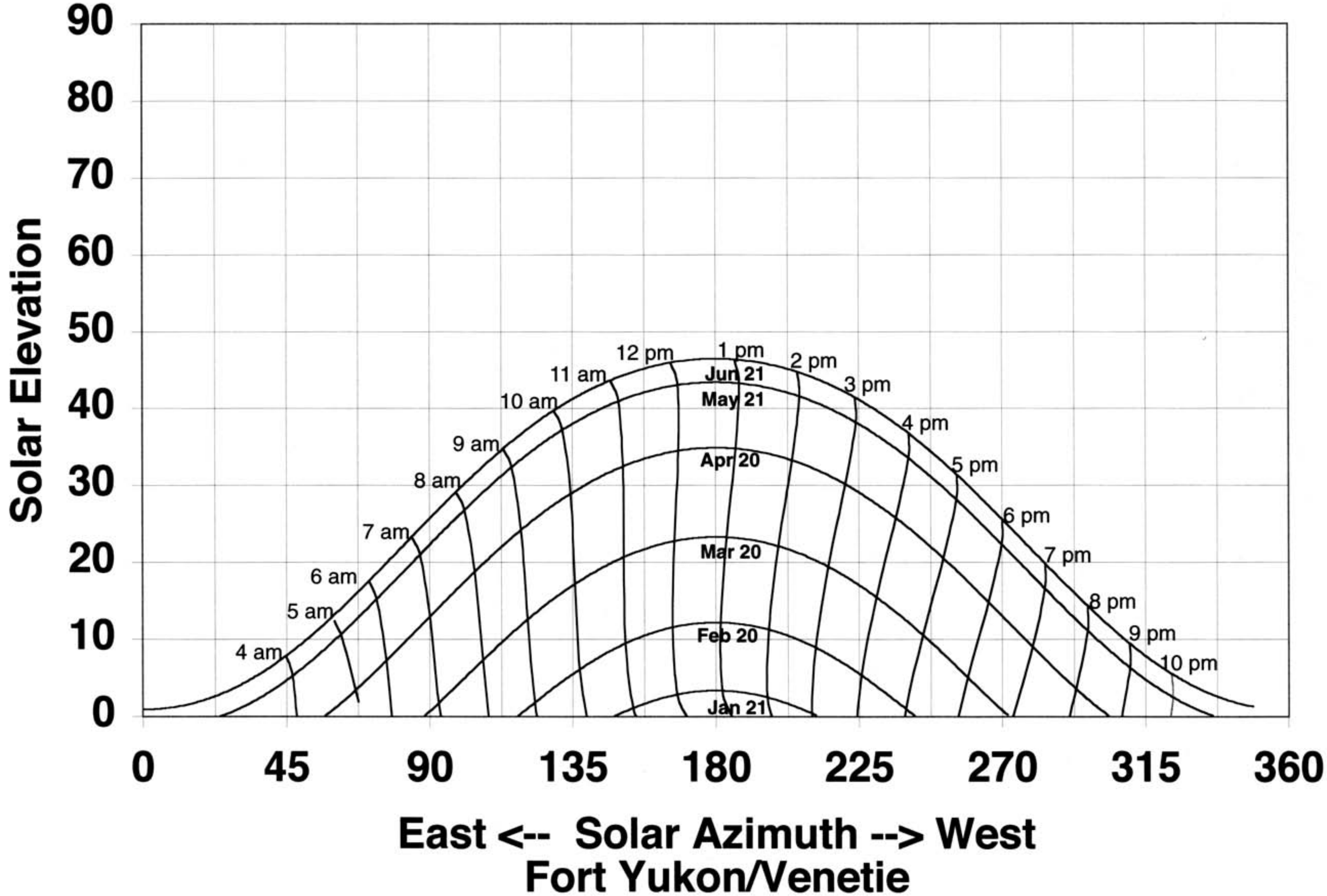

Figure 44. Sun path diagram for Fort Yukon/Venetie, Alaska. Latitude: 67 N; Longitude: 145 W.

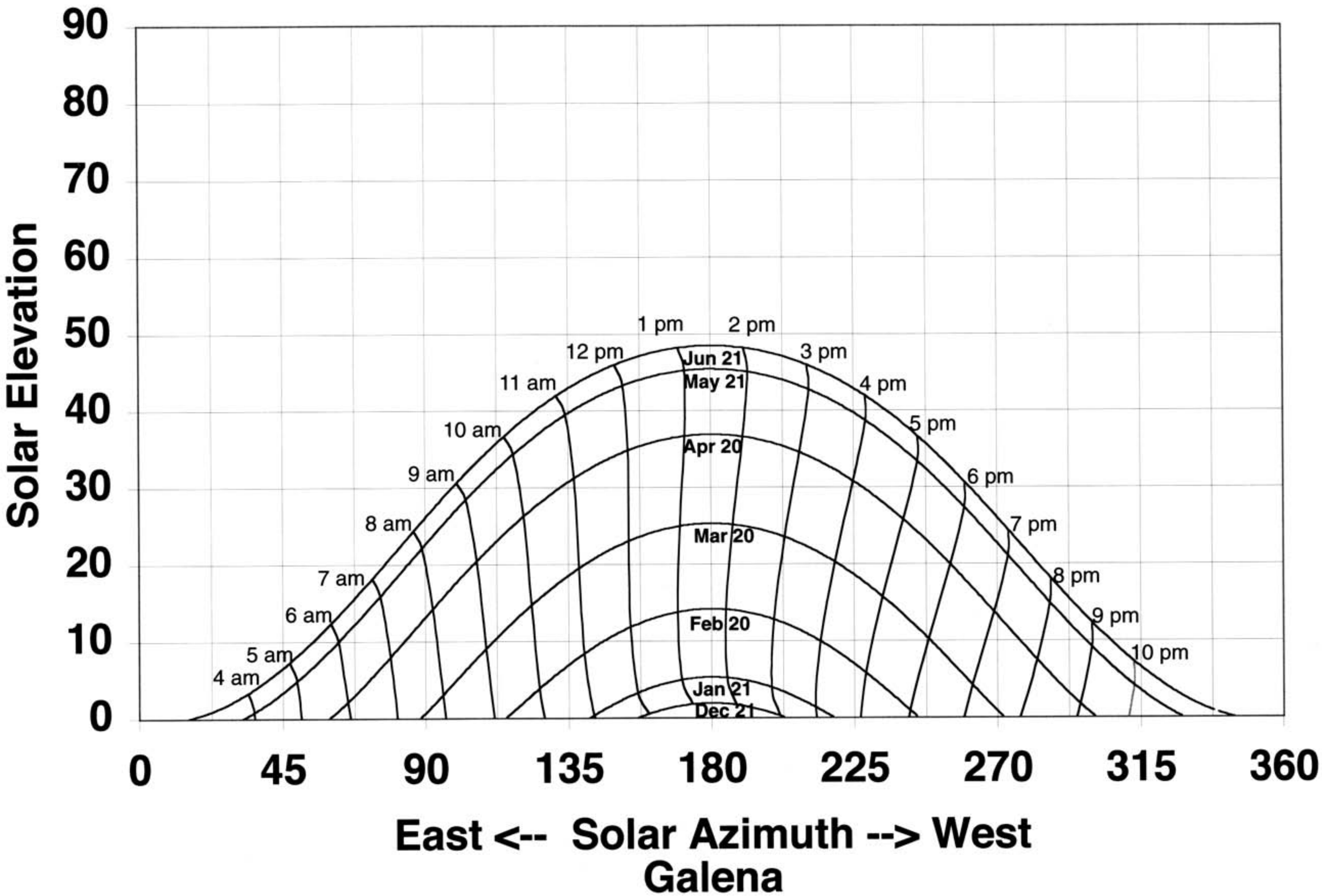

Figure 45. Sun path diagram for Galena, Alaska. Latitude: 65 N; Longitude: 157 W.

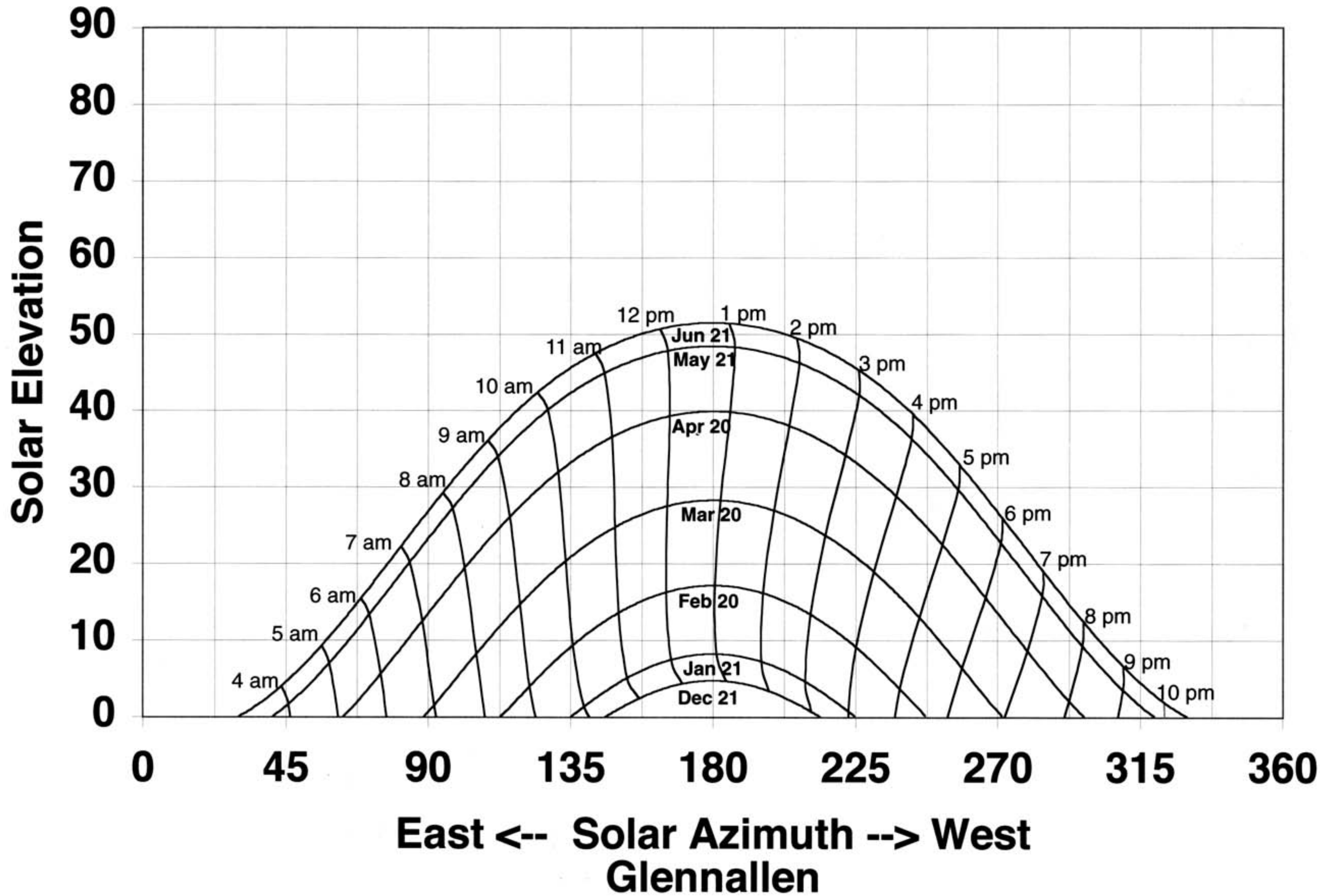

Figure 46. Sun path diagram for Glennallen, Alaska. Latitude: 62 N; Longitude: 146 W.

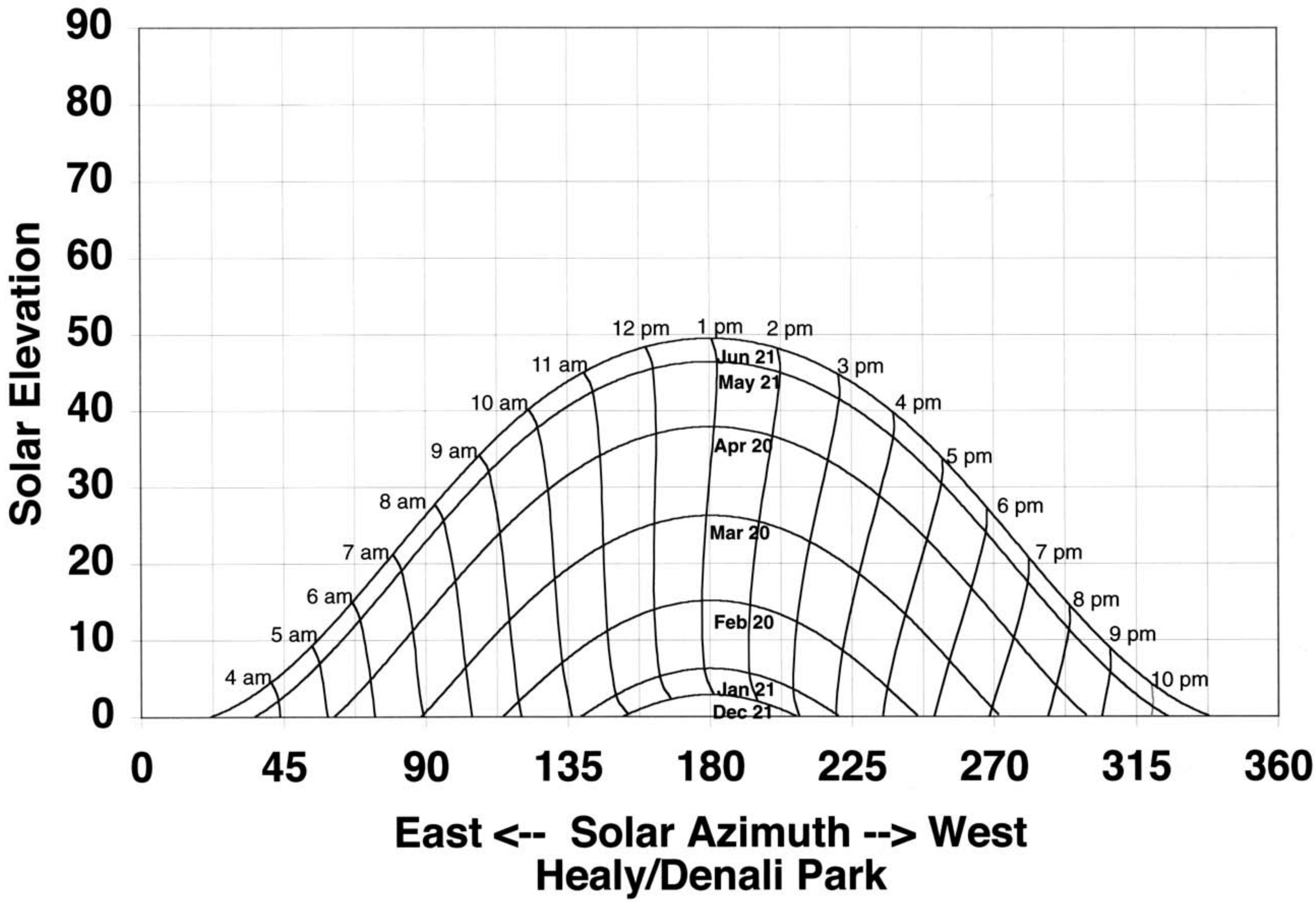

Figure 47. Sun path diagram for Healy/Denali Park, Alaska. Latitude: 64 N; Longitude: 149 W.

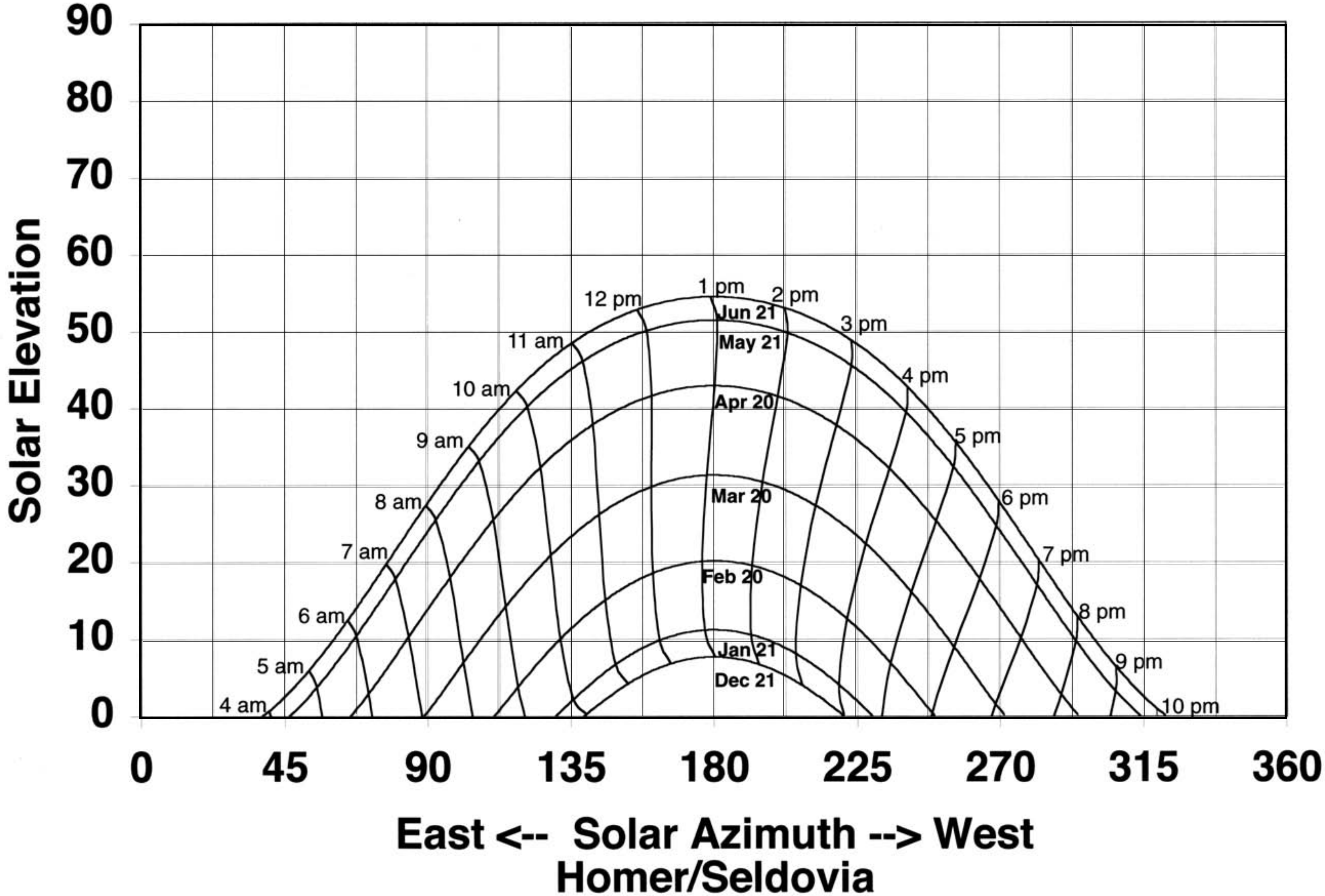

Figure 48. Sun path diagram for Homer/Seldovia, Alaska. Latitude: 59 N; Longitude: 150 W.

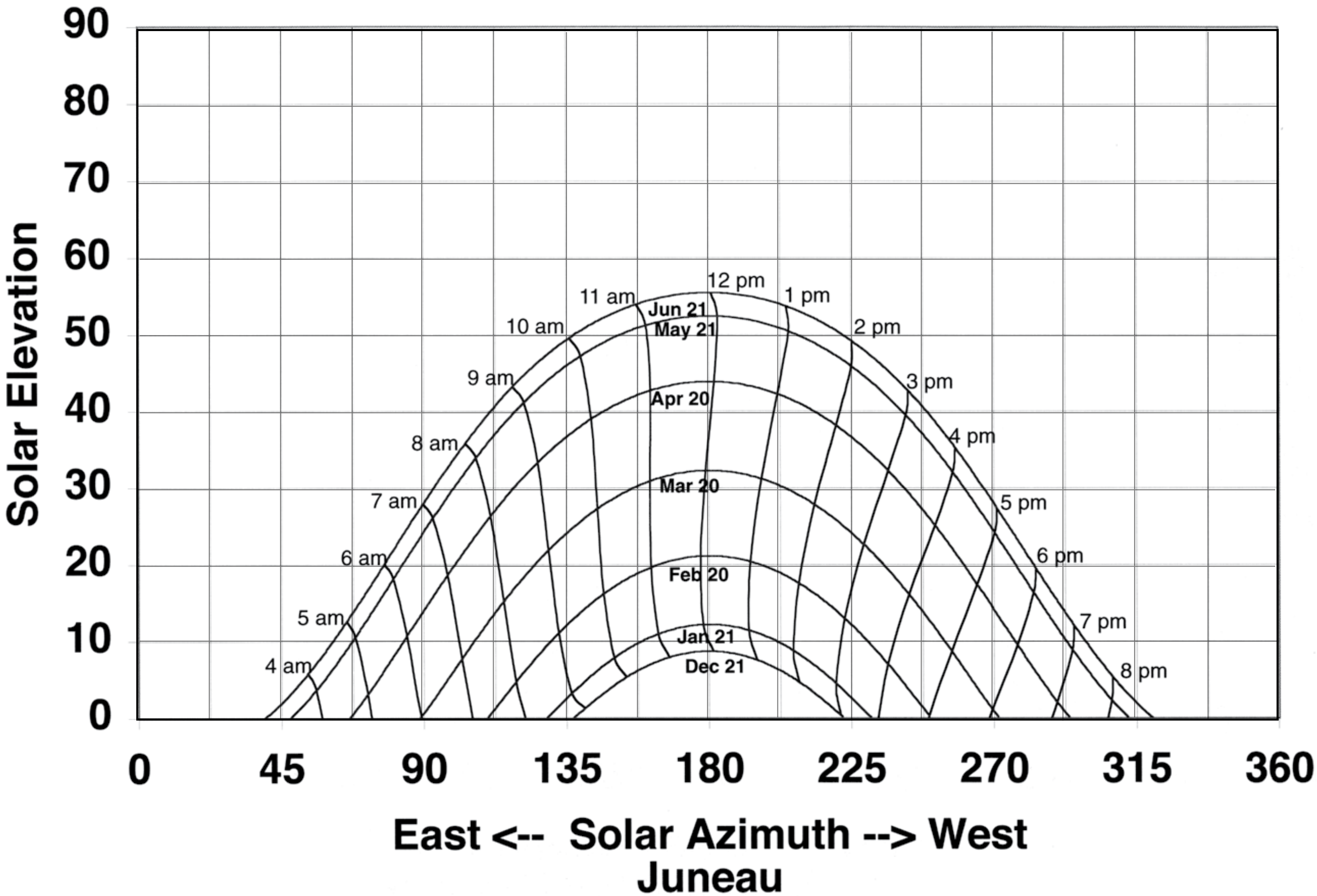

Figure 49. Sun path diagram for Juneau, Alaska. Latitude: 58 N; Longitude: 134 W.

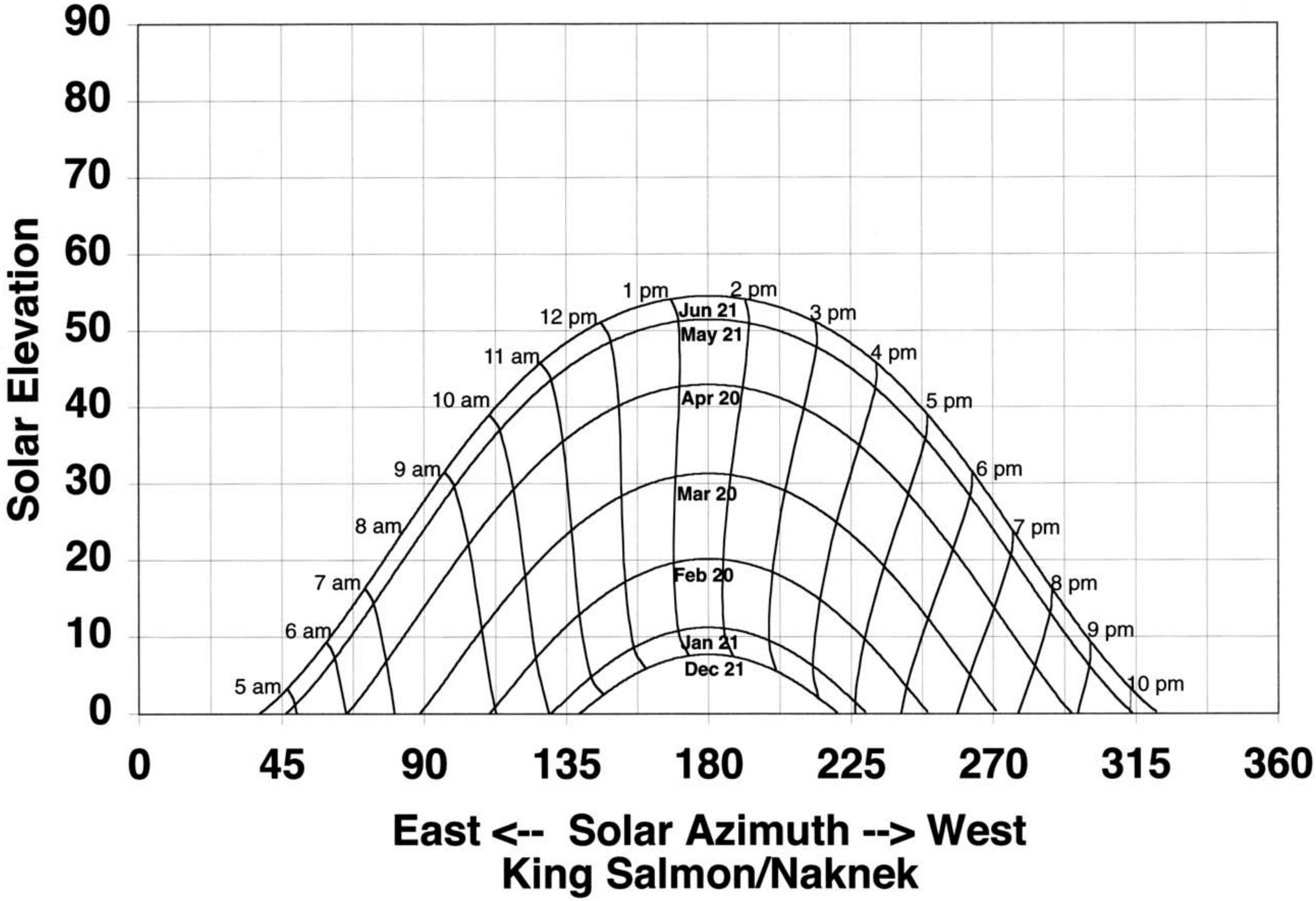

Figure 50. Sun path diagram for King Salmon/Naknek, Alaska. Latitude: 59 N; Longitude: 157 W.

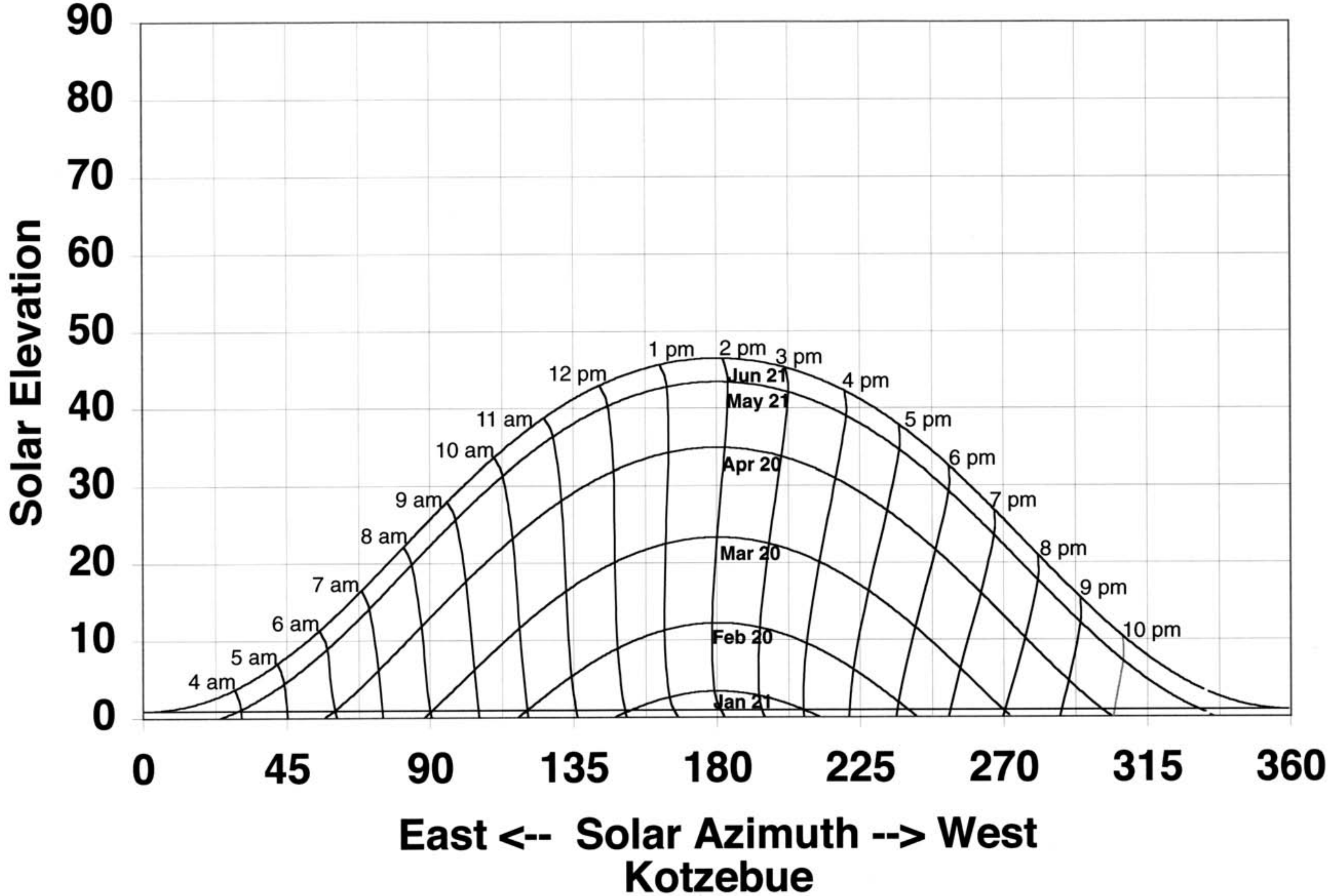

Figure 51. Sun path diagram for Kotzebue, Alaska. Latitude: 67 N; Longitude: 163 W.

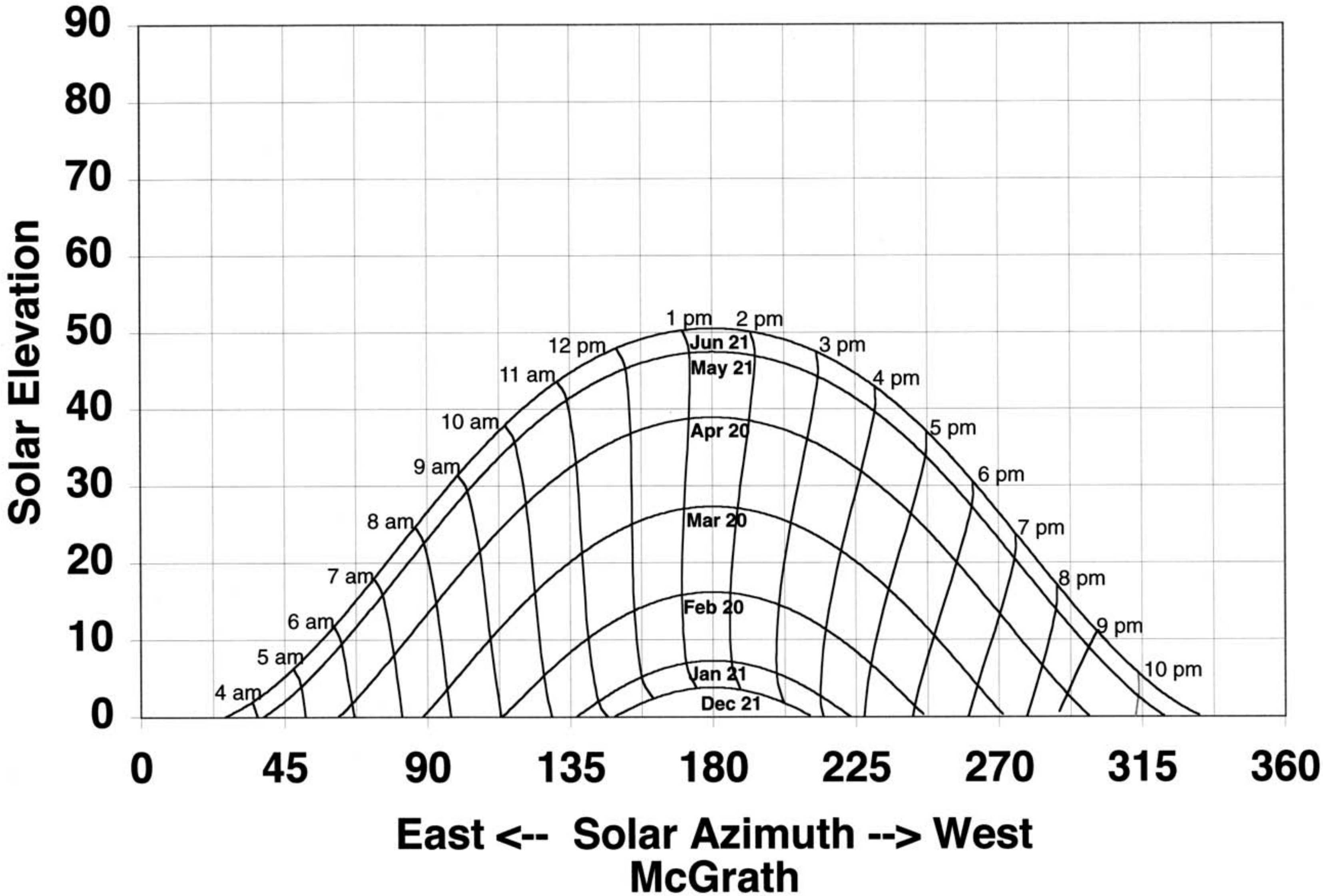

Figure 52. Sun path diagram for McGrath, Alaska. Latitude: 63 N; Longitude: 156 W.

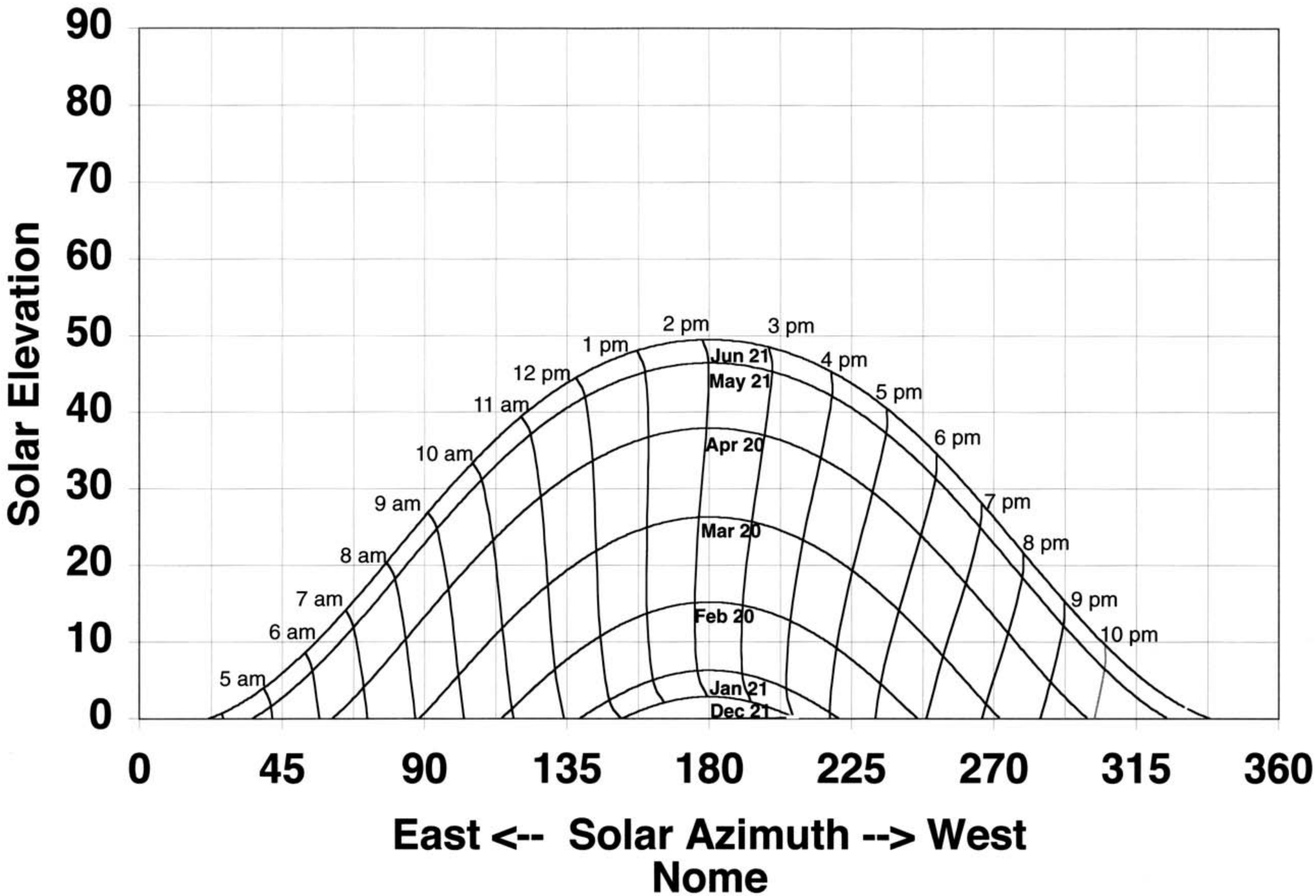

Figure 53. Sun path diagram for Nome, Alaska. Latitude: 64 N; Longitude: 166 W.

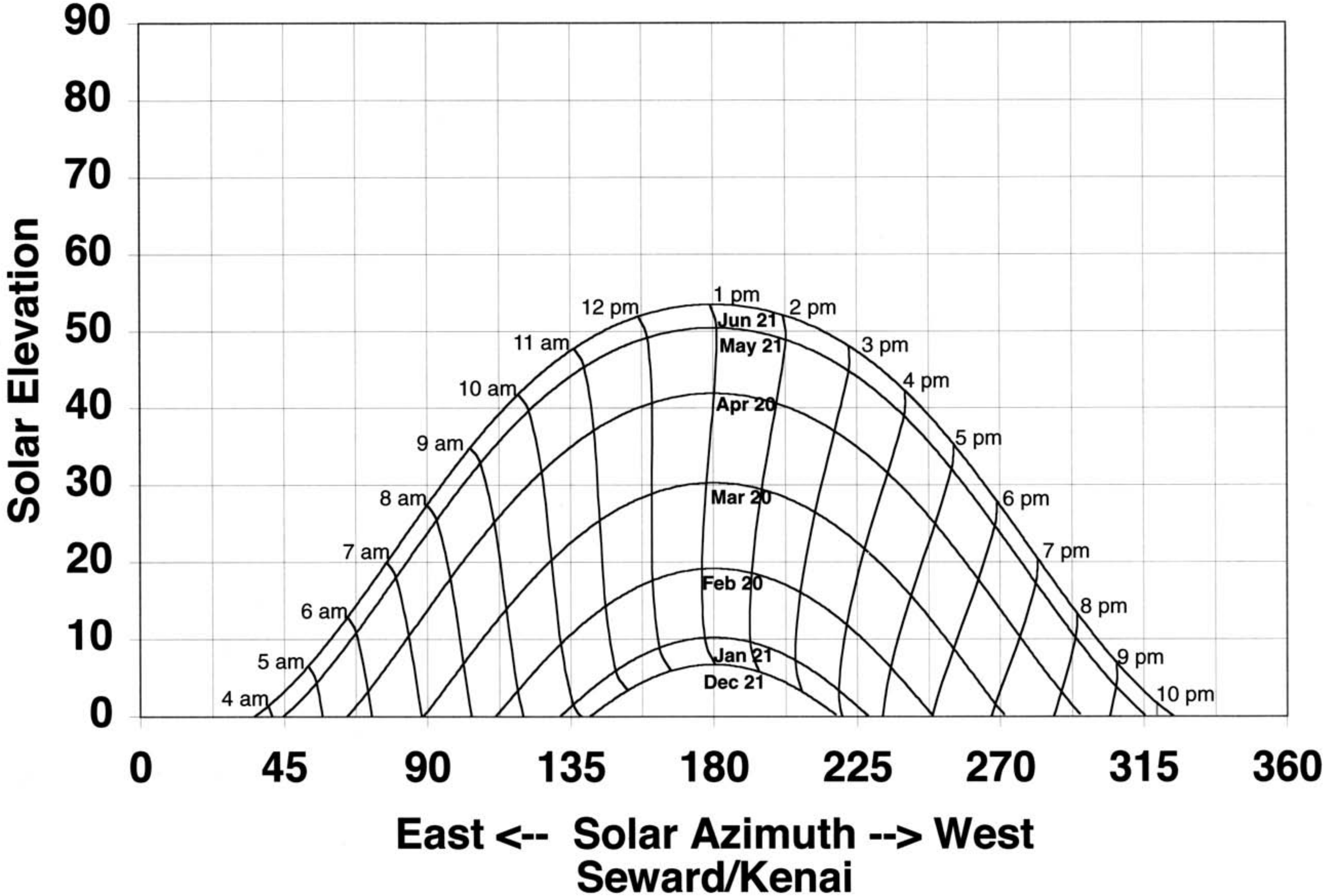

Figure 54. Sun path diagram for Seward/Kenai, Alaska. Latitude: 60 N; Longitude: 150 W.

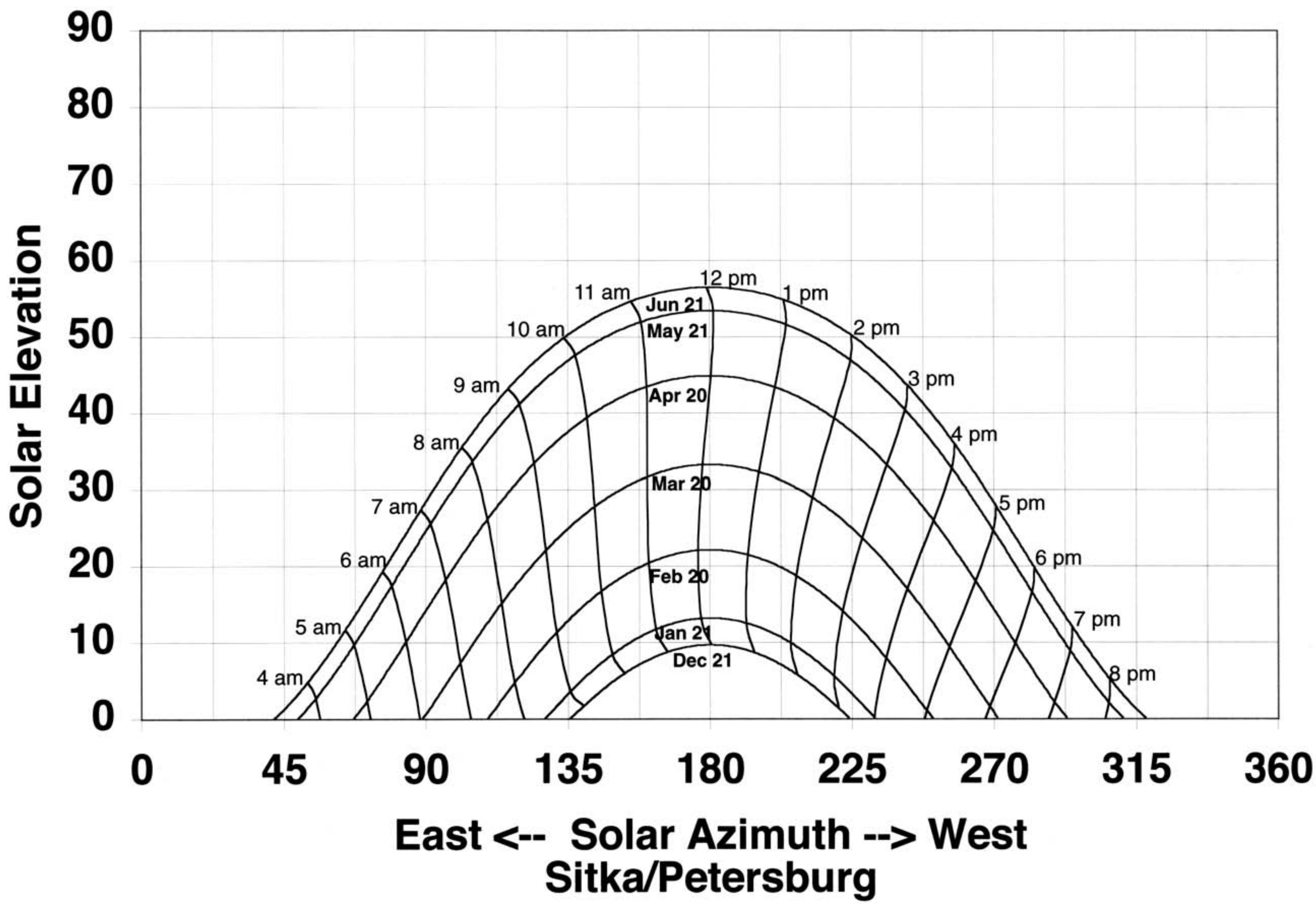

Figure 55. Sun path diagram for Sitka/Petersburg, Alaska. Latitude: 57 N; Longitude: 135 W.

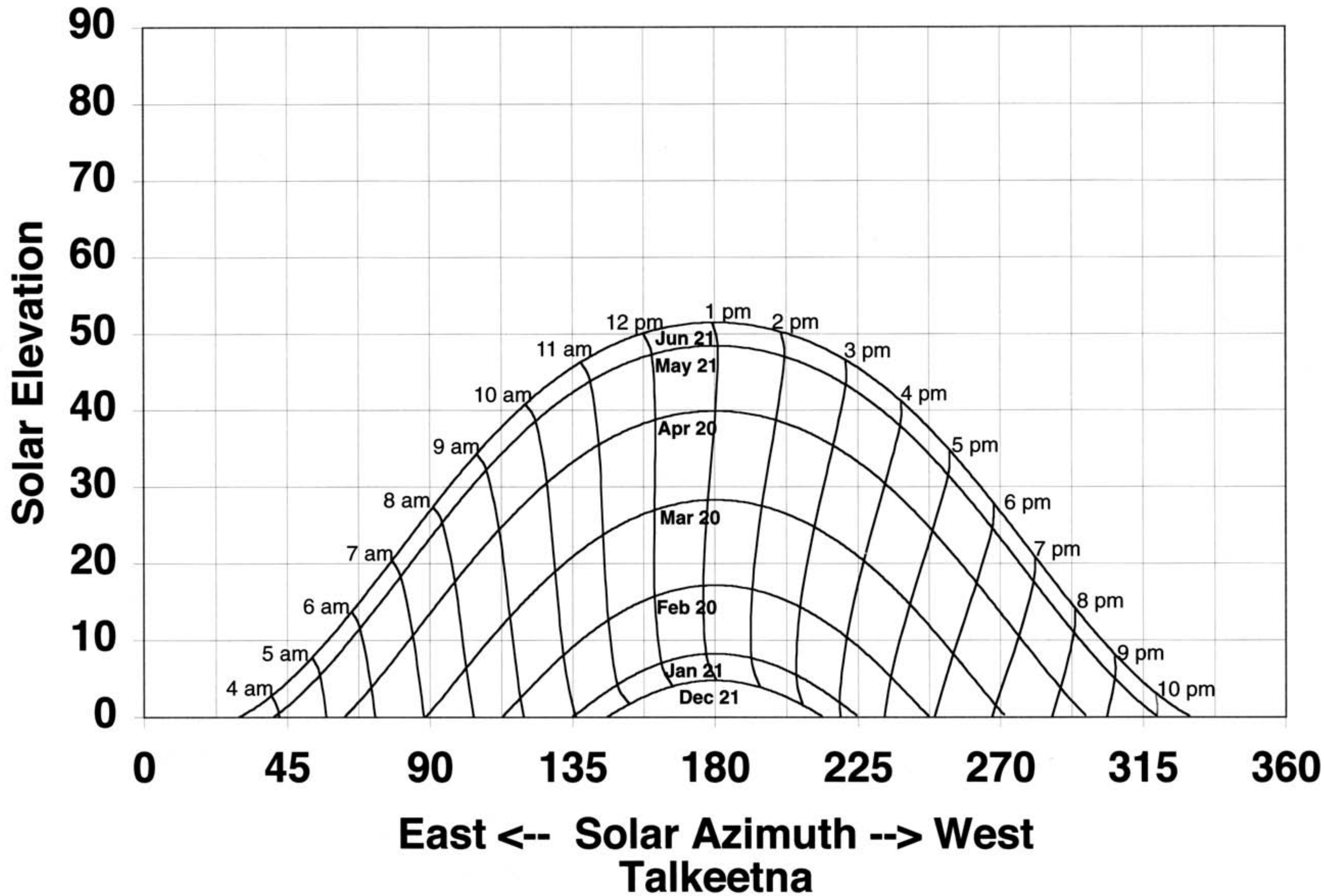

Figure 56. Sun path diagram for Talkeetna, Alaska. Latitude: 62 N; Longitude: 150 W.

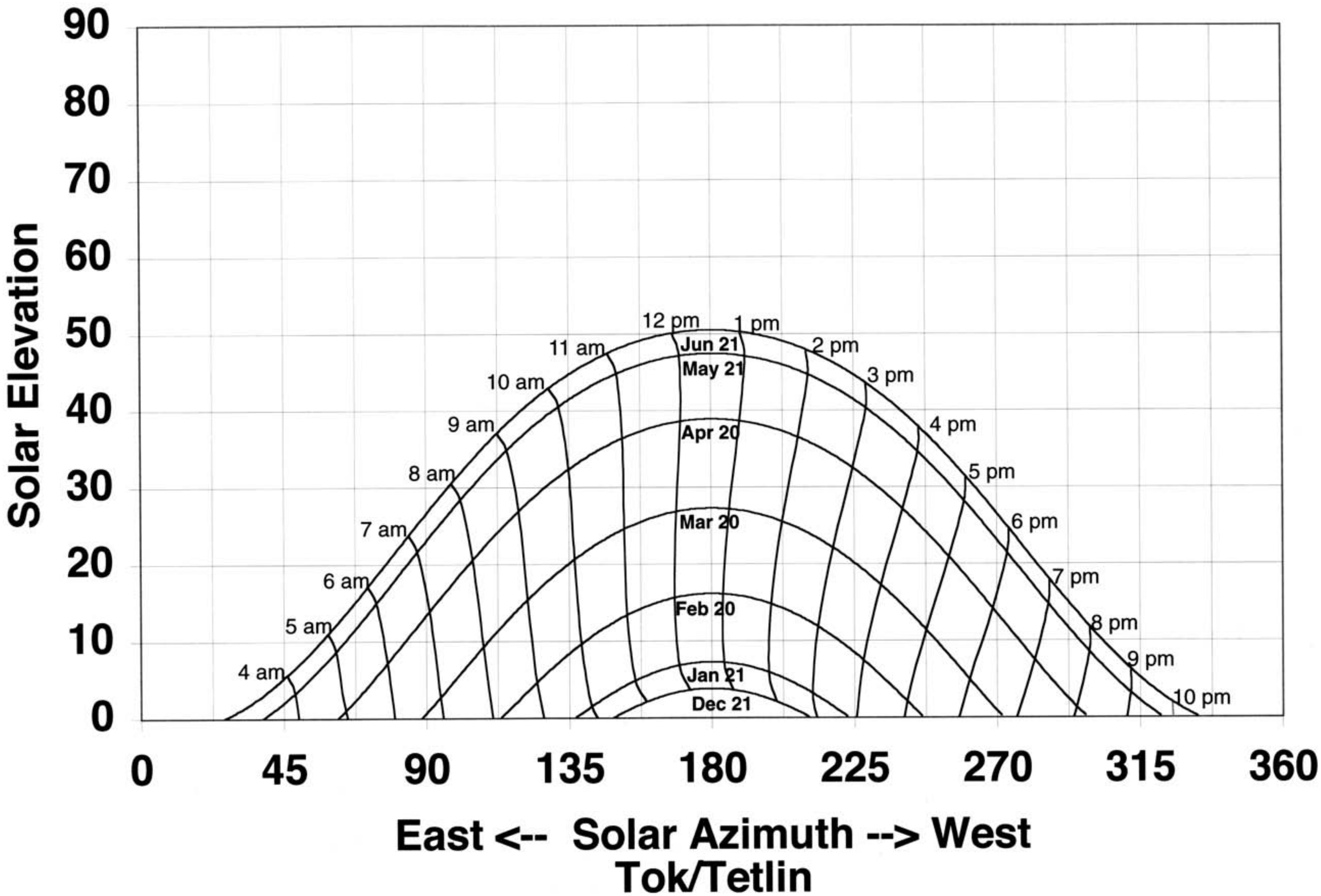

Figure 57. Sun path diagram for Tok/Tetlin, Alaska. Latitude: 63 N; Longitude: 143 W.

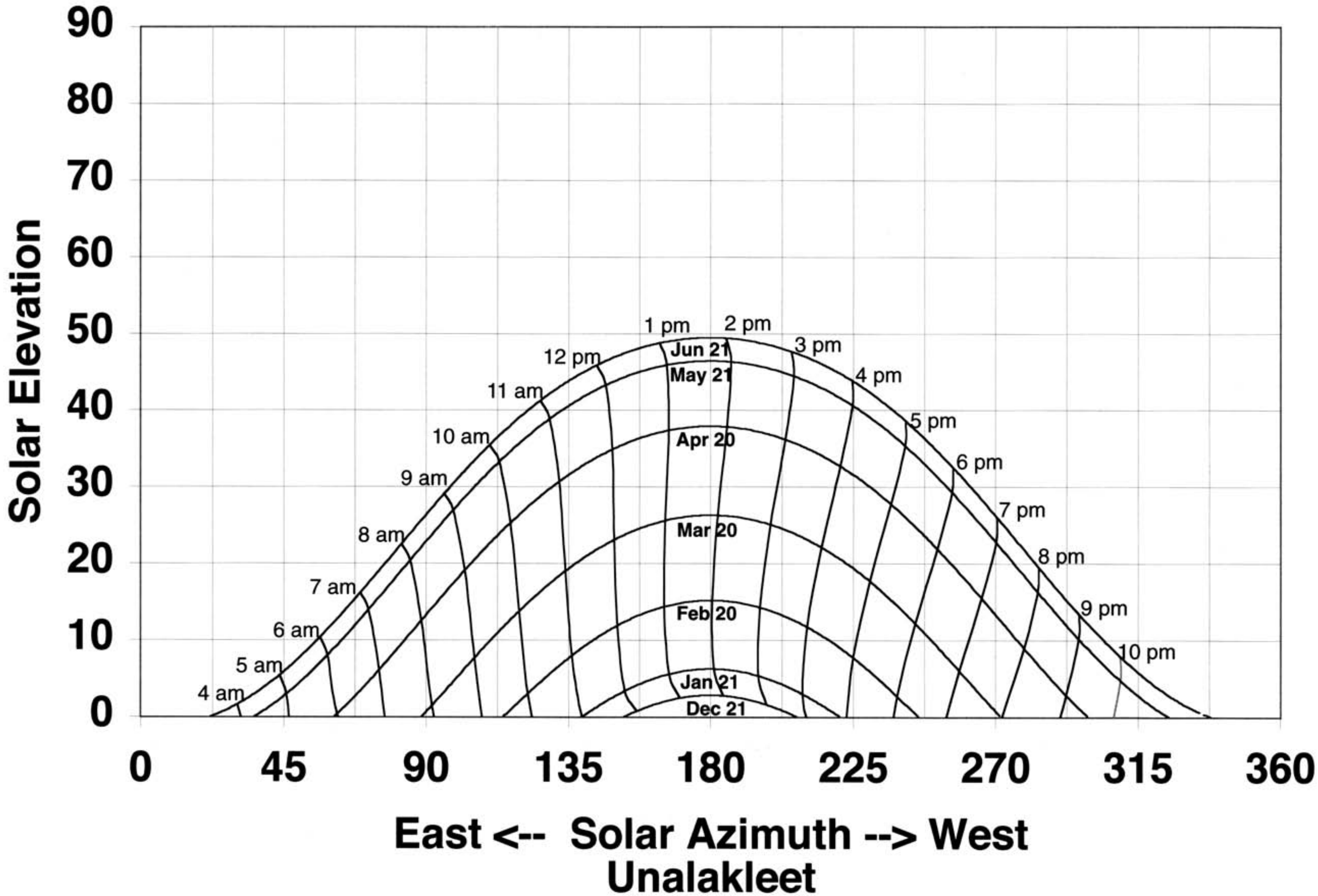

Figure 58. Sun path diagram for Unalakleet, Alaska. Latitude: 64 N; Longitude: 161 W.

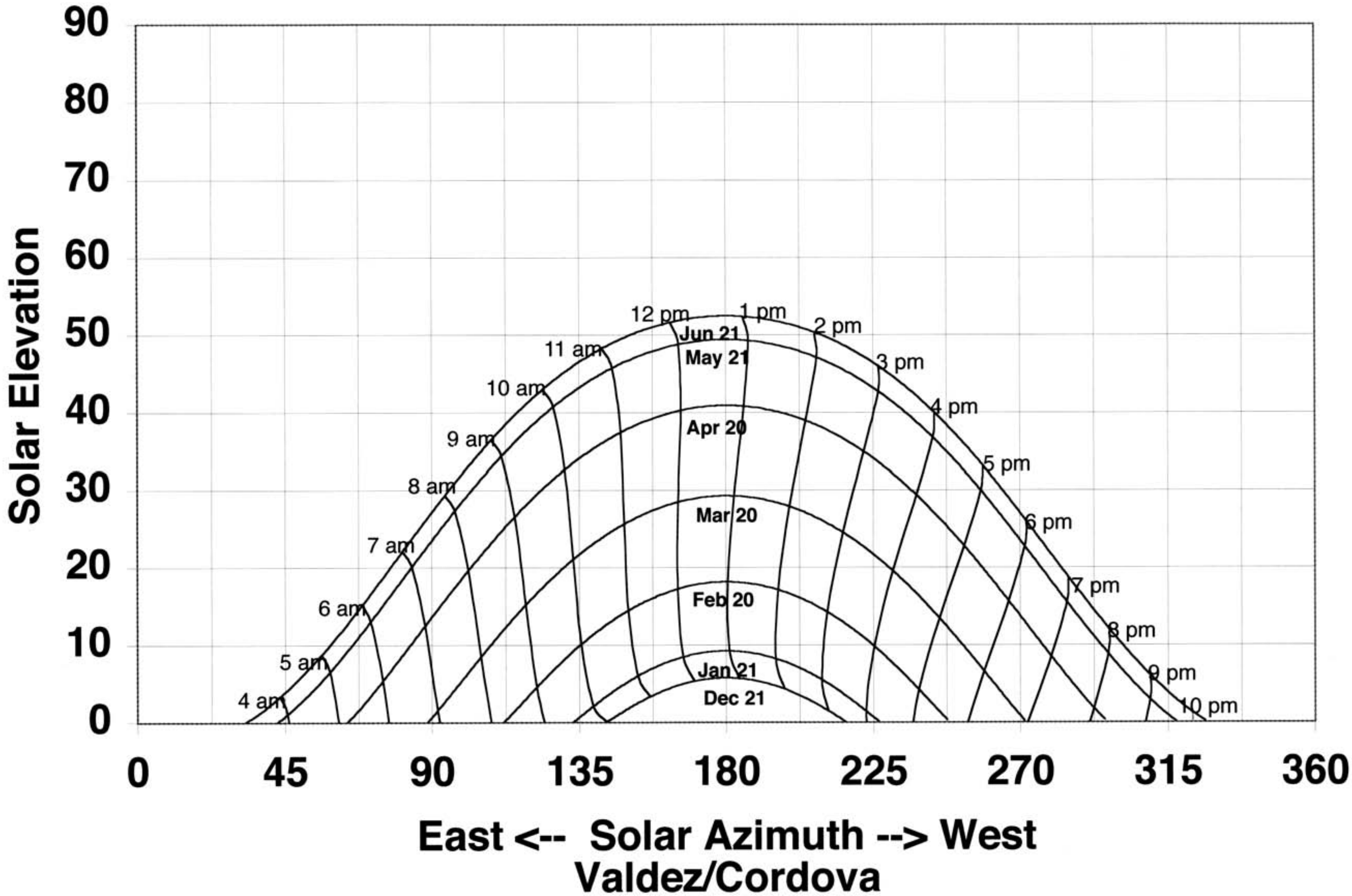

Figure 59. Sun path diagram for Valdez/Cordova, Alaska. Latitude: 61 N; Longitude: 146 W.

New Options for Active Solar Water Heating:

The problem with solar hot water heating is the same as the problem with space heating. The wintertime of the year, particularly the four coldest months of the year, November, December, January and February, are some of the worst months of the year for solar. So anybody who needs to have solar hot water heating available for the winter months is out of luck. A full backup system is needed from some other source than solar, to provide that energy when the sun is just not available to aid in the supply of hot water. This has been a major stumbling block for applications of solar hot water in Alaska.

While this will never be an easy problem to overcome, a larger role for solar hot water active systems may emerge in the future because of the latest development in heating systems, "panel" heating, also called in-slab heating (see Figure 60). This concept delivers heat via plumbing pipes placed in the concrete floors as the building is constructed. These pipes are used to distribute heat, and the floor of the building becomes the heat transfer and delivery medium. These systems have special requirements, which makes them amenable to solar energy as a source of heat.

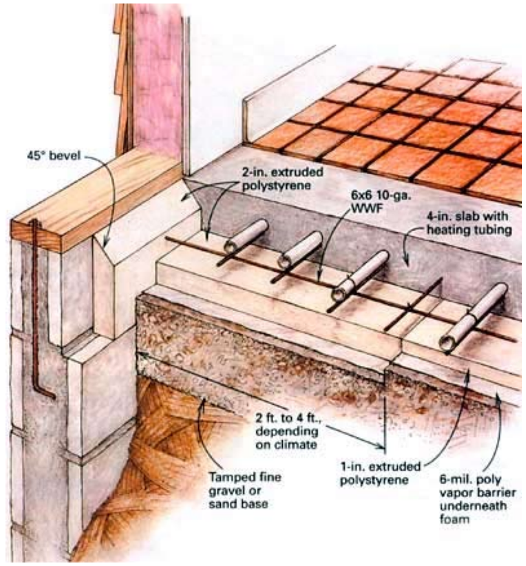

Figure 60. (from Fine Homebuilding Magazine, Taunton Press website: www.taunton.com/finehomebuilding/pages/h00028.asp), a cross section of a panel, in-slab hydronic heating system, amenable for use with solar heated fluid.

Most standard hydronic oil-fired or gas-fired boilers are designed to deliver heat at 160° F. If you are going to deliver this heat into a hydronic tube in a concrete floor, you can immediately glean that delivering heat at 160° F will likely cause great discomfort, first of all, and may even cause thermal expansion to the degree that you can crack the concrete floor. These panel heating systems require delivery of heat at about 110° F. This results in uncannily inefficient applications of hydronic heat. If you heat the fluid for a hydronic heating system up to 160° F only to add tempering water to cool it back down to 110° F, you have a vastly inefficient process.

Solar hot water systems on the other hand, are designed to deliver heat at somewhere around 100° to 120° F and regularly do this. At the very least, they can warm fluids up to a good tempering temperature and provide a large amount of the base load heat even at the 'shoulder' times of the year, say after February 15th throughout the spring and up until about October 15th in the fall. While still not providing ample heat or hot water in the winter, this option adds to the capability of solar active hot water heating by using it as supplemental heat with these new systems.

How much application these options will see remains a matter of conjecture. But as we move toward more efficient, optimal temperature delivery systems for heating our homes, and energy demands decrease because of energy efficiency, any amount of heat available from the sun from an active point of view for both hot water and heating will be useful and environmentally friendlier than fossil-fuel supplied heat. At present, though, it is more expensive than fossil fuels.